AN INTEGRATED DECISION MODEL FOR EVALUATING ALTERNATIVE SWINE WASTE MANAGEMENT SYSTEMS UNDER ENVIRONMENTAL CONSTRAINTS IN OKLAHOMA

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DEDICATION

This dissertation is dedicated to my late parents,

Young-In Kim and Suk-Ja Jeong,

who invested all of their lives

in rearing and educating six children.

I wish you both could have been here

to see me accomplish this goal in my life.

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CHAPTER I

INTRODUCTION

1.1 Problem Statement

Animal production generates waste or by-products such as manure, urine, and wastewater. Advances in livestock production technology have increased the economic efficiency of animal operations. This has allowed increased specialization and intensification of the livestock industry in the United States. With animal production enterprises becoming larger and more intensive, the volume of animal waste processed by each enterprise has also increased. Animal wastes are a useful economic resource when properly applied to fields. Animal wastes contribute nutrients for the crops and enhance the water-holding capacity of the soil. However, manure nutrients can be lost in runoff from fields during heavy rains. Runoff may also contain microorganisms which may impair the use of surface waters for recreation and cause public health problems.

As livestock production operations increase in size, their potential impact on the surrounding environment becomes a more important issue. Most of recent public concern over the Oklahoma livestock industry has focused on swine operations (Ervin, 1997). Increasing public concern about damage to water quality from animal waste has led to the enactment of federal and state legislative laws and regulations to protect surface and groundwater supplies. Federal statutes such as the *Clean Water Act* of 1977 (Public Law 95-217), which was primarily designed to protect the waters from point source pollutants, and the *Coastal Zone Act Reauthorization Amendments* of 1990 (Public Law 101-508), which was designed to reduce non-point pollution, have provided regulatory policies affecting the *concentrated animal feeding operations* (CAFO) and their relations to water quality (USDA SCS, 1992). As a result of such legislation, states have adopted or are currently adopting regulations requiring permits or approvals of waste management systems and nutrient management plans for livestock operations. In the case of Oklahoma, the *Oklahoma Concentrated Animal Feeding Operation Act* (OCAFOA) of 1997 outlines the regulations and penalties for environmental pollution in CAFOs (Oklahoma Statutes, 1997, 9-201). Potential swine producers are especially concerned over impending environmental regulations for handling swine wastes and the possible economic effects on swine production operations.

Swine producers need to find the most profitable waste management system within current environmental regulations. The optimal system may depend on the size of the animal operation, the type of waste system, the land base, and the crops grown. Swine producers have many options with respect to waste collection, storage, treatment, transfer, and application. There is a need to provide both producers and regulators with information about the private and public costs associated with meeting alternative environmental standards. To date, a comprehensive economic analysis of swine production-waste management systems has not been undertaken in Oklahoma.

1.2 Swine Production in Oklahoma

The swine industry in Oklahoma has grown rapidly since 1993 and Oklahoma is currently the state experiencing the most rapid increase in swine production. Estimates reported in *Oklahoma Agricultural Statistics* (Oklahoma Agricultural Statistics Service,

1997) for the total hog inventory as of December 1, 1996, were 1,320,000 head, which ranked 9th in the United States, accounting for approximately 2.4 percent of the total U.S. hog production. This figure had increased by 1,020,000 head since 1993, or an increase of 340 percent in the three-year period. Within Oklahoma, the Panhandle and Central areas of the state have experienced the most rapid growth in swine numbers. Inventories of hogs and pigs in these areas increased by approximately 1,750 percent and 196 percent during the three-year period (1993-1996), respectively. Most of the growth has been in operations over one thousand head. Modern swine production technology involves a package of production technologies including improved genetic breeds, and sophisticated management systems with labor-saving but capital-intensive features which offer economies of size. These systems have been rapidly introduced into Oklahoma because of changes in laws which allow corporate and/or contract operations, interest of the regional economic development groups, favorable climatic conditions, cheaper land cost, and lower labor cost.[1] The number of large scale swine operations will probably continue to increase.

1.3 Study Objectives

The overall objective of this study is to evaluate the economic effects of alternative swine waste management systems on different size of swine production systems. The

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[1] Senate Bill 518, which was enacted by the Oklahoma legislature in April, 1991, removed some restrictions to corporate or contract hog farming in Oklahoma. Corporations planning major expansion programs in Oklahoma include Tyson Foods, Pig Improvement Company, Seaboard Farms, Inc., Farmland Industries, Vall Inc., Murphy Family Farms, Land O'Lakes, and Hanor Inc. For a more detailed description about the status of the Oklahoma swine industry, see Oklahoma Pork Council and OSU (1995) and Luce and Williams (1997).

specific objectives are:

1. To determine the waste management system that maximizes producers' overall profitability and meets current environmental regulations contained in the *Oklahoma Concentrated Animal Feeding Operation Act* (OCAFOA) of 1997.

2. To determine the optimal swine production and waste management strategy (i.e., optimal size of swine production, cropland requirement, and crop selection) which maximizes a particular representative swine producer's overall profitability while meeting environmental regulations on nutrient application rate and volume requirement of waste storage.

1.4 Study Areas

Two study areas were selected in two counties of Oklahoma where there has been a rapid expansion of swine production. As shown the areas of light dark shade in Figure 1-1 and Figure 1-2, one site was selected in Texas county (Oklahoma Panhandle) and the other site was selected in Seminole county (South Central Oklahoma). These sites are quite different in terms of their geographical and climatological features. The geographical, climatic, and managerial characteristics of the study areas are summarized in Table 1-1. The regional aspects of climatological and hydrologic factors are important for specifying waste management options.[2] Texas county has a semi-arid climate, and so the

[2] Potential pollution problems such as rainfall runoff or odor are a function of climate specific to an area. Both water quality and odor problems are affected by temperature, humidity, precipitation, evaporation, and wind patterns. Moist and warm conditions increase the generation of nuisance odors from swine wastes (Day, 1988; MWPS, 1993).

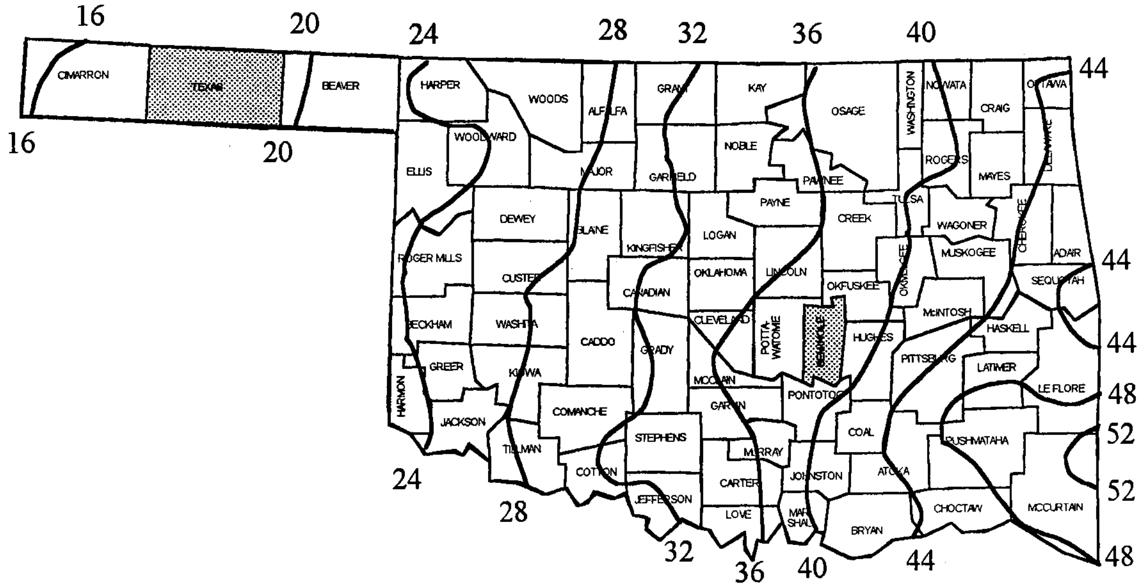

Figure 1-1 Oklahoma mean annual precipitation (inches)

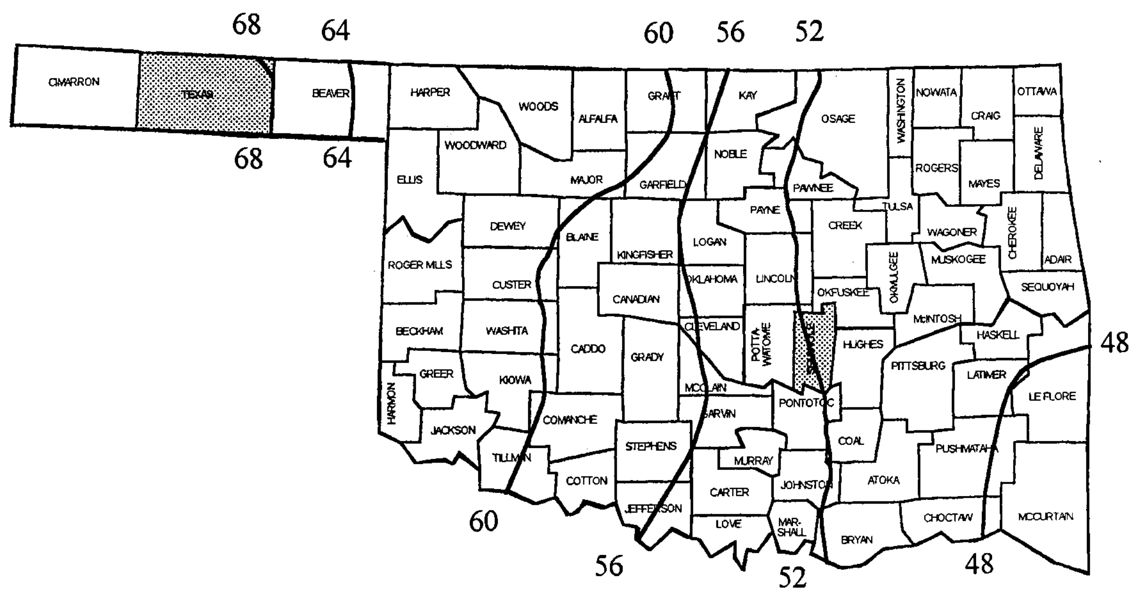

Figure 1-2 Estimated annual lake evaporation (inches)

Table 1-1 Geographic, Climatic, and Managerial Characteristics of Study Areas

	Texas county	Seminole county
Geographic and Climatic Characteristics		
Reporting Stations	Goodwell	Seminole
Location of Reporting Stations[a]		
Latitude	36.60	35.23
Longitude	101.62	96.67
Mean Precipitation, Evaporation (1961-1990)[a]		
Annual precipitation (inches)	18	38
Annual Lake evaporation (inches)	68	52
Net precipitation	-50	-14
25-year, 24-hour rainfall (inches)[a]	5.5 ~ 6.0	5.0 ~ 5.5
Mean AnnualTemperature (°F)[a]	56	61
Soil Characteristics[b]		
Texture	clay, clayloam - Richfield - Potter	drained loamy soil - Stephenville-Darnell - Seminole-Chickasha
Soil Reaction	pH 7.2 ~ 7.5	pH 5.1 ~7.0
Managerial Characteristics		
Major crop production[c]	Corn, Wheat, Sorghum	Wheat, Hay
Yield for irrigated wheat (bushel/acre)	37.7	30.0
Yield for corn (bushel/acre)	182.5	-
Yield for irrigated sorghum (bushel/acre)	97.5	-
Yield for all hay (tons/acre)	-	1.94
Number of farms[d]	704	872
Average size of farm (acres)[d]	1,493	288
Major production firm[e]	DeKalb Swine Breeders, Inc. Hitch Pork Producers and Vall, Inc. Seaboard Farms	Tyson Foods, Inc.

Source: [a] Johnson and Duchon (1994).
[b] USDA (1961, 1979).
[c] Oklahoma Agricultural Statistics Service (1997).
[d] Census Bureau (1996).
[e] Luce and Williams (1997).

average humidity of this area is low and the rate of evaporation is high. The average annual rainfall based on a 30-year record at Goodwell Oklahoma from 1961 to 1990 was about 18 inches, while the average lake evaporation was 68 inches from 1961 to 1990. The average annual net precipitation, which is defined as the annual rainfall minus annual evaporation, is a negative 50 inches. Water to irrigate crops on the uplands is supplied by deep wells. Wheat and grain sorghum are the principal non-irrigated crops, while corn, wheat and grain sorghum are the principal irrigated crops (Oklahoma Department of Agriculture, 1991). Most agriculture in the county is practiced on a large scale. The 704 farms average 1,493 acres per farm according to the 1992 Census of Agriculture (Census Bureau, 1996).

Seminole county has a relatively humid climate. The average annual precipitation at Seminole is about 38 inches while annual lake evaporation is 52 inches (Johnson and Duchon, 1994). Average annual net precipitation is about negative 14 inches. Wheat and hay are the major crops. Most agriculture in the county is of a medium scale. The 872 farms averaged 288 acres per farm according to the 1992 Census of Agriculture (Census Bureau, 1996).

Soil types and climatic conditions are evaluated to determine average conditions for the site of the swine operation specified. These characteristics are then used to determine crop nutrient requirements and nutrient loss estimates. The predominant soils are characterized as clay and clayloam in Texas county (Richfield soil), and drained loamy soil in Seminole county (Darnell soil).

Based on the geographical and managerial characteristics, representative swine operations for the study sites are developed according to size of animal and cropland, and labor availability. Luce and Williams (1997) report that DeKalb Swine Breeders, Inc., Seaboard Farms Inc., Hitch Enterprises, and Vall Inc. have operations in Texas county, while Tyson Foods Inc. has operations in Seminole county.

1.5 Methods of the Study

The waste handling system is but one component of an overall swine production and waste management system. The whole system approach is useful where changes to one component (like waste management) of a system affect other components of the system. An integrated production-waste management decision model is developed using mathematical programming. The swine producer is assumed to maximize profit. The producer is assumed to be a price taker for inputs and outputs. A mixed integer programming is used for major analytical tool since this programming model can be used to represent the continuous and discontinuous natures of engineering and economic reality. Models of this type allow selecting the best-practice waste management system from a group of feasible alternatives given the resources of a particular swine operator. Specific environmental regulatory constraints limit swine production and waste management decisions. In addition to the main analytical model, several smaller subsidiary models, based on the economic engineering methods, are used to compute various cost and technical coefficients for use in the main models. Data to determine model coefficients are obtained from the official reports, previous studies, personal communication, local contractors and distributors of equipment and facilities, and the

EPIC (Erosion Productivity Impact Calculator; Williams, 1990) simulation model. The integrated decision models developed in this study are programmed and solved in the GAMS (General Algebraic Modeling System; Brooke, Kendrick, and Meeraus, 1996) package.

1.6 Organization of the Thesis

A review of the relevant literature is contained in the next chapter. Chapter III outlines background information concerning economic and environmental problems in handling swine wastes. Chapter IV describes the conceptual framework and methodology of the integrated decision model using a mathematical programming. The mixed integer linear programming model and its data requirements are presented in Chapter V. Results from the model are discussed in Chapter VI. Conclusions, limitations of the study, and further research agenda are presented in Chapter VII. The GAMS program code for the integrated decision model developed in this study is contained in the Appendix.

CHAPTER II

REVIEW OF LITERATURE

The need to manage animal waste has led to significant research efforts aimed at minimizing environmental problems and at maximizing producers' profitability. A significant amount of economic research specific to swine waste management has been conducted and approached from different sides depending on the goals of the research. This section of literature review discusses and evaluates conducted research having similarities and relevance to the objectives mentioned in the previous section. Selected studies were broadly separated into two main categories depending on the analytical techniques used such as budgeting and mathematical programming.[3]

2.1. Budgeting (or Economic Engineering) Approach

Research to evaluate costs and returns associated with various waste management systems begins with the budgeting (or economic engineering) method. Kesler (1966) used the economic engineering method to evaluate alternative swine waste handling systems for various sizes of growing-finishing hog operations in Illinois. Costs of manure handling equipment and credits for fertilizer nutrients were included in the budgeting framework. The results showed that hauling and spreading was the lowest cost method of disposing of liquid swine manure when cropland was available and the manure was used to replace

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[3] Considerable economic research pertaining to livestock waste management and pollution control has been conducted. In recent years the environmental and economic issues in swine waste management have been well documented in several proceedings (Storm and Casey, 1994; Iowa State University , 1995, and; Council for Agricultural Science and Technology, 1996).

commercial fertilizer. The lagoon method was the highest cost method since few nutrients were recovered from the manure. Similarly, Morris (1971) used budgeting to compare the cost of an oxidation ditch and crop application with the use of manure as an animal feed. The results showed that there was no one best system but that the choice depended upon the species, fertilizer price, and the environment.

Badger and Cross (1971) also used budgeting based on survey data to examine the technical, legal, and economic aspects of the Oklahoma Feed Yards Act of 1969 on confined beef and swine feeding operations. The researchers found machinery costs to be the most important component of total waste handling expense. Badger and Cross also found that average total costs were reduced converting from solid feeding floors to slatted floors and lagoons.

White and Forster (1978) completed an economic and environmental assessment of 59 dairy, 45 beef, 70 swine, 35 sheep, 35 poultry waste management systems. The researchers used a budgeting approach to evaluate the costs and benefits of various manure handling systems. White and Forster concluded that waste treatment by lagoon and land application of the effluent by irrigation to be the most cost effective method of pollution control for larger animal operations. However, the best practices for reducing the runoff potential and odor problems of waste were either plowdown or direct injection of wastes into the soil.

Crews (1987) developed a spreadsheet program model to assist in the design and economic evaluation of alternative waste management systems. The spreadsheet model included the collection, transfer, treatment, storage and distribution phases of handling swine wastes from any type of production system. Systems were compared on the basis of the cost of operating and annualized ownership costs and the accrued nutrient benefits of the waste. Storage ponds, anaerobic lagoons (one and two stage), and aerobic lagoons were analyzed for a 500 head feeder pig-finishing operation. The results showed that the anaerobic lagoon with a grass filter system had the lowest investment requirements, while outside storage pits recorded the highest. Crews found that recycling of wastewater used for flushing reduced the annual net costs by over one-third and estimated the economies of size for all production phases and treatment storage systems.

Sutton, Foster, Underdown, Jones, and Sutton (1993) used a partial budgeting approach to compare the costs of various swine waste management systems for a 1,100 head growing-finishing hog operation. The researchers compared economic costs of alternative storage systems such as deep pit storage, outside storage system (tank or pits), and lagoons. The results showed that the slurry tank system with a shallow pit had the highest original construction and storage costs, but also had the highest return for fertilizer nutrients. In contrast, the lagoon system with a shallow pit had the lowest original construction and storage costs, but had the lowest return for fertilizer nutrients. The researchers concluded that management is a key factor to the success of any manure management system and there is no one best system for all situations.

Babcock, Fleming and Bundy (1997) compared the costs of covering outside earthen storage basins and anaerobic lagoons with using immediate incorporation of manure into the soil to reduce odor problems in Iowa. The results showed the annual cost of covering a storage basin with a durable plastic cover was $2.99 per breeding sow and

$1.02 per market hog, while the annual cost for covering an anaerobic lagoon was $11.07 per breeding sow and $6.15 per market hog. The incremental cost of requiring incorporation with land application was $1.39 per breeding sow and $0.68 per market hog for lagoon systems and $0.49 per breeding sow and $0.17 per market hog for manure stored in basins or pits. Study results implied that the cost of complying with both regulations would fall most heavily on operations that use lagoons and that the magnitude of the costs involved were large enough to make the lagoon systems unprofitable in Iowa.

The studies using budgeting mentioned above are incomplete in evaluating the profitability of alternative waste management systems since it does not cover overall impacts of environmental regulations and resource constraint on swine production system.

2.2. Mathematical Programming Approach

Optimal swine production and waste management systems can be selected with linear and mixed integer programming models. Safley, Haith, and Price (1979) developed both linear and mixed integer linear programming models as decision tools for selecting dairy manure handling systems. The linear programming (LP) determines the optimum manure handling system from a group of feasible alternatives, given the resources of a particular farm. The decision variables in the LP model included the number of animals, the amount of hired and operator labor, energy requirements, and fertilizer requirements. The mixed integer linear programming (MILP) model was designed to help determine the best manure handling practices while maintaining normal agricultural practices and constraining potential environmental pollution. The decision variables in this model included soil-crop combination and manure spreading as binary variables and amount of nitrogen fertilizer applied to cropland, and herd size as continuous variables. This study was notable in that it incorporated both economic and environmental factors (e.g., nutrient runoff losses and soil erosion factors) into the system for analysis.

Stonehouse and Narayanan (1984) used a linear programming model to evaluate alternative manure-handling systems for a pre-specified livestock and cropping situation. Results showed that farmers who manage livestock manures in a manner that maximized retention of plant nutrients could reduce fertility costs as compared to producers who purchased only chemical fertilizers.

Westphal, Lanyon, and Partenheimer (1989) used an LP model to evaluate the effects of various plant nutrient management strategies for corn and alfalfa crop sequences on optimum dairy herd size and net farm returns. They considered unrestricted manure applications and application restricted to nutrient levels usable by the crop. Optimal animal densities were shown to vary as nutrient management strategies changed. The researchers concluded that there was a need to evaluate a farm as a whole so that relationships between enterprises could be evaluated.

Amir and Ogilvie (1977) developed a mixed integer programming model for selecting an optimal waste management system in eastern Canada which minimized the annual manure handling operating cost subject to capital, labor and swine manure volume limitations. Herd sizes of 300, 500, 800, and 1,000 head were specified and post optimal sensitivity analyses were conducted. The results showed that no single swine manure handling system was optimal for all the herd sizes. The researchers found the system with a fully slotted floor, under-floor pit, and pumping to a slurry tank for land application was the second best solution for all herd sizes considered.

Drynan, Williamson, Westerman, and Crane (1981) used mixed integer linear programming to determine the least-cost manure management systems for North Carolina hog operations. The study analyzed feeder pig finishing operations, feeder pig production operations, and the farrow to finish operations. In addition, the major storage facilities, and land application options for liquid swine manure were identified and investment and operating costs were estimated. The researchers found the totally slotted floor-anaerobic lagoon-irrigation system was the most profitable in North Carolina and that choosing the wrong system or using a system inappropriately could increase costs by 70 to 80 cents per 100 lbs liveweight marketed. The researchers emphasized the opportunity costs of making the wrong decision about the waste management system, although the waste management cost of an efficient system is a relatively minor cost in terms of the total system cost.

Brundin and Rodhe (1994) selected among alternative waste management systems for Swedish dairy and hog operations by using mixed integer programming. The objective of the mixed integer programming model was to maximize net present value. The results showed that the costs of non-uniform application and soil compaction are economically important. The researchers found the tradeoff relationship between nitrogen utilization , timeliness and soil compaction to be of great importance.

Brundin (1994) developed a mixed integer nonlinear programming model to find the profit maximizing design and system for manure handling on cattle and pig farms in central Sweden. Nonlinear crop response functions to nitrogen and timeliness were included in the programming model. Brundin concluded that the slurry tanker with a pendular nozzle to be the most profitable system for all farms with 20 to 160 dairy cows or 250 to 2500 pigs. The profitability of manure handling systems was found to depend on the quantity of manure and on the type of soil.

Mathematical programming, such as mixed integer programming and linear programming models, has been found useful in selecting economically viable strategies for handling manure for many sizes of operations and soil types when any number of additional constraints are on the system. Linear and mixed integer programming are used as the major analytical tools in this study.

CHAPTER III

ENVIRONMENTAL AND ECONOMIC ISSUES IN HANDLING SWINE WASTE

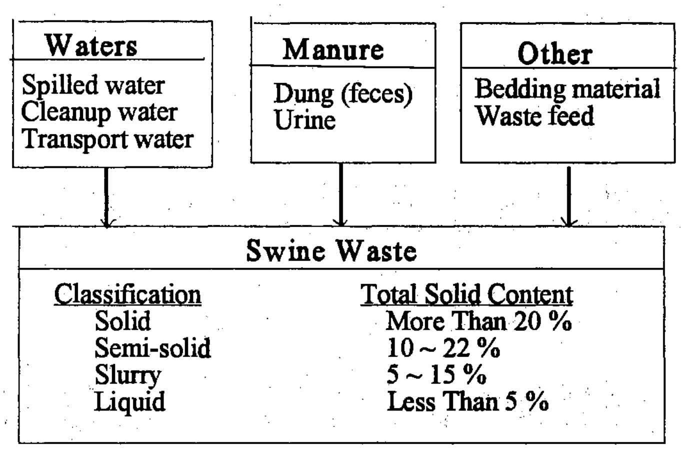
This chapter outlines background information concerning the environmental and economic issues in handling swine waste. The properties of swine waste are briefly described. The environmental and economic problems of swine waste disposal are described as an externality. Both federal and state environmental regulations and programs for swine waste management are presented. The various swine waste management systems combine alternative waste storage and application systems.

3.1. Properties of Swine Waste

An understanding of the properties of swine manure and/or waste is necessary in order to develop an adequate waste management system. The terms of swine manure and waste are sometimes used synonymously in the literature. In this study, swine manure refers to combinations of feces and urine only, and swine waste includes manure plus other material, such as bedding, wasted feed, and water that is wasted or used for sanitary and flushing purposes of swine waste. The most common types of swine waste are classified as solid, semi-solid, slurry, and liquid. The difference is drawn from the consistency of total solid content, as shown in Figure 3-1. The category of swine waste is an important factor in selecting the waste management system.

Swine manure consists of approximately 60 percent feces and 40 percent of urine (Hamilton, Luce, and Heald, 1997). The properties of swine manure are classified primarily as physical, chemical, and biological. These properties are significantly affected by many factors such as the physiology (size, sex, breed, and activity) of the animal, the feed ration (digestibility and the protein and fiber content), and the climatic environment (temperature and humidity).[4] The total amount of liquid manure to be handled is largely influenced by the type of operation and particularly wastage of water. Daily generation rate and major characteristics of swine manure from each type of animal are given in Table 3-1. Daily manure quantity which generally increases with animal weight ranges from 3.7 pounds (equivalently 0.056 cu.ft. in volume) for a nursery pig to 26.0 pounds (equivalently 0.41 cu.ft.) for a sow and litter. The figures in Table 3.1 can be used as parameters to calculate the amount of manure produced in each stage of swine production. The total

Figure 3.1 Components and Classification of Swine Waste



Sources: Adapted from Day (1988) and USDA SCS (1992)

[4] For more detailed description about the characteristics of swine manure, see Miner and Smith (1975), Day (1988), USDA SCS (1992), and Midwest Plan Service (1993).

amount of liquid to be handled can be affected by wastage from waters, and can equal 20 percent of manure generation (MWPS, 1993).

The major causes of pollution from swine manure are oxygen-demanding bacteria and nutrients sources of water. The pollution potential of swine manure can be measured by the BOD_5 (5-day biochemical oxygen demand). BOD_5 is defined by the quantity of oxygen needed to satisfy biochemical oxidation of organic matter in waste sample in 5 days at 68 °F (USDA SCS, 1992). As shown in Table 3.1, the average BOD_5 of a finishing pig is 0.47 pound per day, which is approximately 100 times greater than that of municipal sewage (Muehling, 1971).

Swine manure contains major fertilizer nutrients such as nitrogen, phosphorus, and potassium. The fertilizer nutrients come from the feeds consumed by the animal. Raw

Table 3-1 Daily Production Rate and Characteristics of Swine Manure As Excreted

Type	Size	Manure production		TS[1]	VS[1]	BOD_5	Nutrient content,lb/day		
	(lb)	lb/day	cu.ft/day	lb/day	lb/day		N	P_2O_5	K_2O
Nursery	35	2.3	0.04	0.39	0.30	0.11	0.02	0.012	0.012
Growing	65	4.2	0.07	0.72	0.55	0.20	0.03	0.022	0.023
Finishing	150	9.8	0.16	1.65	1.28	0.47	0.07	0.050	0.054
Gestating	275	9.0	0.15	0.82	0.66	0.27	0.07	0.050	0.050
Sow/litter	375	22.5	0.36	2.05	1.64	0.68	0.10	0.055	0.055
Boar	350	11.5	0.19	1.04	0.84	0.34	0.09	0.064	0.064

1) The acronym TS and VS represent total solid and volatile solid, respectively.
Source: MWPS (1993).

swine manure is about 0.7 percent nitrogen, 0.5 percent phosphorus and 0.5 percent potassium, as shown in Table 3-1. The rate of nutrients contained in raw manure depend on the method of collection, the type and length of storage, and on the method and time of application. Nutrients in swine manure can be lost during collection, handling and storage. The losses are attributed to volatilization, leaching, percolation, runoff and wind or water erosion. The nutrients in swine manure as applied are in fixed proportion which do not directly match the nutrient requirements of crops. The net economic value of swine waste is reduced by the costs of collection and storage, and the transport to cropland.

Roka and Hoag (1996) showed that because of high transportation and incorporation costs, swine manure value is negative ($1.03/head) even under the most favorable conditions. This implies that swine manure is a waste product. In reality, some runoff and leaching of manure nutrients is a natural consequence of swine feeding operations, but potential pollution problems caused by swine wastes are generally intensified by two factors such as improper waste handling and animal density.[5] If manure is improperly managed during storage and application, excessive nutrients are released into the environment which may result in contamination of surface water and groundwater sources.

Furthermore, since major crops such as corn and wheat need relatively more nitrogen than phosphorus, applying swine manure to satisfy crop nitrogen needs usually

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[5] The physical presence of pollution does not mean that an economic pollution exists. The economic definition of pollution depends upon some physical effect of waste on the environment and a human reaction to that physical effect. The physical effect can be biological, chemical, or auditory. The human reaction shows up as an expression of distaste, unpleasantness, distress, concern, and anxiety and can be represented as a loss of welfare (Pearce and Turner, 1990, pp.61-62).

implies that phosphorus and potassium are supplied in excess of crop needs. Potential adverse soil effects from excess manure applications include nutrient imbalances, excessively high accumulations of some minerals, and salt buildups. Increasing animal density relative to the availability of cropland has led to the overproduction of nutrients relative their use as a fertilizer. Accordingly, over application of swine waste for extended periods of time can cause the build-up of phosphorus in the soil to levels that seriously affect the productivity of the land (Mathers and Stewart, 1980)

From the environmental perspective, there exists a controversy regarding the effect on the environment of swine manure disposal. Some people argue that manure nutrients enhance environmental quality when they are used in place of commercial fertilizer while other people argue that manure nutrients pose a potential threat to pollution of surface and groundwater and that nuisance odors arise from improper handling and disposal of swine manure. The proponents of sustainable agriculture argue that dichotomy disappears with the best waste management practices which minimize nutrient leakages to the environment (Glover, 1996; Leston and Gollehon, 1996; Heitschmidt, Short, and Grings, 1996). In short, swine manure from a viewpoint of nutrient management can be either a valuable economic resource or a major pollutant, depending on how it is managed. Swine manure could be used as a fuel, livestock feed, or as a fertilizer substitute (Harper and Seckler, 1975; Fontenot and Ross, 1980). This study will focus on a fertilizer substitute of swine waste from land application perspective.

3.2. Environmental Economic Problems of Swine Waste Disposal

The potential pollution problems resulting from swine waste disposal could be summarized as the nutrient runoff to surface water, seepage to ground water sources, soil erosion, and/or nuisance odor. These problems are highly variable and are dependent upon the climate, soils, and production system. The environmental problems associated with managing swine waste are examples of a market failure phenomenon. The market fails to assign values for environmental damage so these costs are external (not paid by swine producers) and result in an externality.[6] The negative externalities occur when (1) improper land application allows excess nitrogen and/or phosphorus to leach into the groundwater or contaminate the surface water, and (2) the release of ammonia and other compounds into the air leads to air pollution. The producers have an incentive to ignore environmental damages because the price received is the same regardless of whether or not swine wastes were managed properly. The market does not reward producers who may operate environmentally sound but perhaps unprofitable practices.

The major purpose of environmental policy is to correct negative externalities. The main environmental policy instrument for controlling swine waste management has traditionally used the command-and-control approach which directly regulates polluters through the use of rules or standards. Under this approach, the regulatory authority sets an environmental standard (target) and the polluter is required to honor the standard,

[6] An externality is defined as "a spillover effect associated with either production or consumption of a good or service that extends outside the market to some third party other than the producer or consumer of that good or service." If the external effect generates costs (benefits) to a third party, it is called a negative (positive) externality (Callan and Thomas, 1996, p.82).

under the threat of some penalty.

In order to diagrammatically show the optimal level of externality, consider a representative swine producer who is a profit maximizer or, implicitly a cost-minimizer.[7] Swine producers will consider all feasible waste management options and select the least-cost manure management system to meet the environmental regulatory standards. Basically, swine operations can reduce pollution by scaling back polluting activities (or decreasing the size of swine production operations) or by diverting resources to reduce pollution. In the latter case, the pollution reducing activity will entail costs for installing and operating an abatement technology.

In Figure 3-2, the horizontal axis represents the level of waste generation measured from left to right and the level of pollution abatement measured from left to right as well as swine production. Costs in monetary terms are shown on the vertical axis. Environmental regulations of swine operations should encourage installing waste management systems. A marginal abatement cost (MAC) function is developed to allow swine producers to choose from various alternative waste management systems. This represents the change in costs from the most cost effective system from removing or treating increasing quantities of a pollutant. The estimation of abatement cost in a swine production management system is based on the producer's direct and indirect costs of installing and operating waste handling equipment. The MAC function slopes upward

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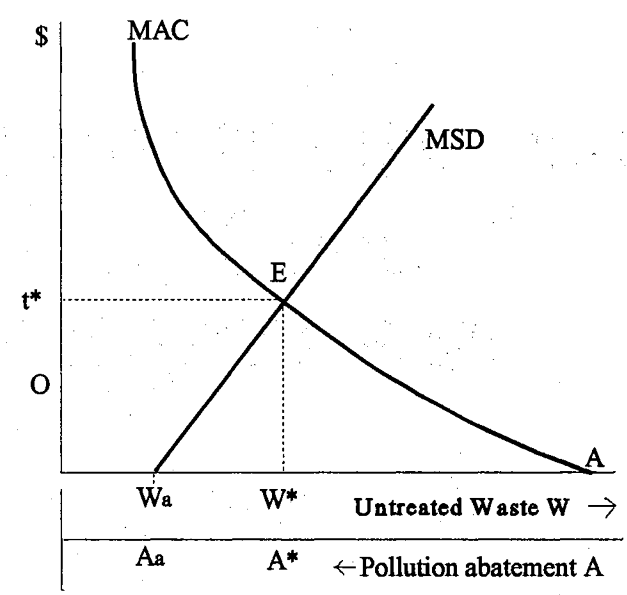
[7] A representative swine producer who uses the cheapest possible method of handling swine waste to satisfy a given technology-based standard will not be maximizing profits unless the chosen output level is the one which maximizes profits. Thus, profit maximization implies cost minimization, but the converse is not necessary true.

right to left at an increasing rate because there are diminishing returns to pollution abatement. The position and slopes of the MAC functions are affected by several factors such as the size of operations, the average operating efficiency, and the efficiency of waste management technology.

The marginal social damage (MSD) cost is the value of damage done by pollution arising from the additional swine production. Conceptually, the MSD curves represent a vertical summation of the individual curves of willingness-to-pay to avoid the damages associated with the indicated levels of waste emissions. Such a curve thus depends both upon the production site and people affected and their tastes. This curve is usually drawn for a fixed level of production and thus a fixed amount of waste generated. As shown in Figure 3-2, the horizontal axis measures the amount of untreated waste (→) and amount of

Figure 3-2. Optimal Level of Swine Waste Generation and Pollution Abatement Cost



pollution removed abated from the waste (←). Figure 3-2 shows how the level of swine production activity relates to the levels of waste disposed and pollution abated. The initial quantity of swine waste is directly proportional to the level of swine production in a given environment. Recognizing the role of the natural environment as a receptor of waste disposal, the potential environmental damages begin at the threshold level W_a, where the capacity of the environment to assimilate waste is exceeded. The optimal level of negative externality is where these two curves intersect. In this framework, W^* is the optimal level of untreated waste or remaining pollution. Accordingly, the first-best environmental policy instrument such as an optimal tax (t^*) or quantity regulation (W^*) could be imposed to reach the level of optimal pollution.

The measurement of the social damage cost from swine pollution is difficult. Measurement of health and other effects such as recreation and aesthetics are subject to much uncertainty. Under limited and incomplete information on the social damage from swine pollution, the second-best policies could be designed to minimize the cost of achieving some reasonable target of abatement. This is referred to as the cost-effectiveness analysis (CEA) has been conducted to ensure that the least cost solution is identified for each possible level of environmental output (Callan and Thomas, 1996). In the absence of a common measurement unit of comparing the non-monetary benefits with the monetary costs of environmental plans, the CEA is a valuable tool to assist in decision making. Once that objective is specified, the CEA can have a great deal to say about the cost consequences of choosing a means of achieving that objective.

Typically several means of achieving the specified objective are available, some will be relatively inexpensive, while others turn out to be very expensive. The problems are frequently complicated enough that identifying the least-cost method to achieve an objective can not be accomplished without analyzing alternatives subject to constraints. The CEA frequently involves optimization procedures (Tietenberg, 1992). In this context, an optimization procedure is merely a systematic approach of finding the lowest-cost means of accomplishing the objective. Notice that this procedure does not, in general, produce an efficient allocation because the predetermined objective may not be efficient. All efficient waste management systems are cost-effective, but not all cost-effective systems are efficient.

3.3. Environmental Regulations and Programs for Swine Waste Management

Swine producers in the United States can be regulated in order to maintain or improve environmental quality in many different ways, from federal regulations to state and local laws. The regulatory framework and rules must be understood before discussing the impacts of environmental regulations on swine operators.

3.3.1. Federal Environmental Regulations and Policy Programs

Two important federal environmental statutes, the *Clean Water Act* (CWA) of 1972 and the *Coastal Zone Act Reauthorization Amendments* of 1990 (CZARA), regulate water pollution control on animal feeding operations including swine production (Copeland, 1994).

The CWA was originally enacted by Congress in 1972 and has since been amended several times. Its objective is to reduce or eliminate water pollution in the nation's rivers, streams, lakes, and coastal waters. The CWA employs variety of mechanisms to control agricultural pollution. The CWA prohibits the discharge of any pollutants into the nation's waterways from a point source unless authorized by a permit from the appropriate agency. The Act delegated the authority to administer the law to the U.S. Environmental Protection Agency (EPA).[8] The CWA requires each state to adopt water quality standards for most water bodies located within the state's borders (Copeland, 1994). The standards are used to establish water quality based treatment controls and strategies to protect the water quality. Discharges of waste from point sources into navigable waters are regulated through the mandatory permit system known as the *National Pollution Discharge Elimination System* (NPDES).[9] Permits are issued either by EPA or by the state under a program approved by EPA. It is illegal to discharge waste from point sources into navigable waters (or nation's waters) without a permit. The permit issuance process normally involves the submitting an application, an agency review of the application for completeness, a tentative permit decision by the agency, time for public comment or a hearing, and the final permit decision. This permit system provides major impetus for the establishment of federal water quality guidelines affecting animal feeding operations. Under the CWA, concentrated animal feeding operations (CAFOs) are

[8] Federal environmental laws are passed by the U.S. Congress and are implemented through regional environmental protection agency (EPA) offices. The EPA implements the point source provisions of the Act through the NPDES regulations (Federal Register, March 18,1976).

[9] The policies and procedures for issuing the NPDES permits were published by the U.S. EPA on May 22, 1973. On July 12, 1976, final regulations were published for livestock production activities defined as point sources of pollution. For a more detailed description about the NPDES program, see USDA SCS (1992, pp.1.3~.1.4) and Copeland (1994, pp.2-6).

considered as point sources and therefore require permits.[10] A CAFO is a lot or a facility where animals are confined or maintained for a total of 45 days or more in any 12-month period, and the confinement area does not sustain vegetation (USDA SCS, 1992). The CAFO owners/operators must obtain an NPDES permit if they fall under any of following categories:

1) Any feedlot having more than 1,000 animal units, i.e., over 2,500 head of swine weighing over 55 pounds equivalent to 0.4 animal unit.[11]

2) Any feedlot having more than 300 animal units (i.e., over 750 head of swine) and discharging waste directly into waters of the United States.

3) The regional administrator of the EPA or the director of the state program may make site by site designations requiring permits from smaller feedlots that contribute significantly to pollution of any surface water.

The EPA required each state to develop a livestock waste management program that was at least as restrictive as the federal program. In 1993, the EPA Region VI developed a general feedlot permit for Louisiana, New Mexico, Texas, and Oklahoma which overrode the state permit approach. Most environmental regulatory agencies have authority to inspect any swine feeding operation that is suspected of being a pollution

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[10] The term "point source" means any single identifiable source of pollution such as a fixed location or facility from which contaminants are discharged (Callan and Thomas, 1996, p.425). Thus, the source pollutants are included any pipe, ditch, channel, tunnel, well, container, rolling stock, CAFO, or other floating craft.

[11] In the Clean Water Act (CWA), the animal unit is a mean by which different types of animals can be compared. Animal units are computed as the number of slaughter and feeder cattle multiplied by 1.0 or the number of swine over 55 pounds multiplied by 0.4.

hazard, but inspection and enforcement usually are limited to a response to a complaint.[12]

However, a swine feeding operation does not need an NPDES permit if it discharges only as a result of a 25-year, 24-hour storm event (USDA SCS OK and et al., 1993). If a pollutant discharge into waters of the U.S. occurs and the swine operation does not have a required permit, an owner or operator may be fined. Failure to comply with the terms of the NPDES permit can result in civil and criminal fines, each up to $25,000 per day of violation. The NPDES permit sets effluent limitation guidelines that must be met.

Further identification of regulatory concern is related to the nonpoint source pollutants. The *Coast Zone Act Reauthorization Amendments* (CZARA) (Public Law 101-508, 1990) were enacted to protect the natural, commercial, recreational, ecological, industrial, and aesthetic resources of the coastal areas of the United States. In addition, the 1987 Amendments to the CWA (Public Law 100-4, Section 319, February 4, 1987) also focused on nonpoint source pollution. Control programs under the CZARA and the CWA Amendment are to be carried out by implementing a prescribed set of waste management measures. States are required to adopt management measures commonly called "best management practices" (BMPs) to reduce the nonpoint source pollution and to develop a program to implement BMPs. The BMPs include a set of recommended input use levels, nutrient management plans and animal manure management practices which consider both environmental and economic factors. BMPs reduce nonpoint animal

[12] The inspection and enforcement of an environmental regulatory agencies were explained by Copeland (1994).

pollution by identifying management practices which animal feeding operators should adopt and then regulatory authorities provide producers with economic incentives to implement these practices. Under those acts, swine feeding operations have been identified as a nonpoint source of pollution affecting rivers, lakes, and wetlands since the application of manure solids and lagoon effluent to pasture and cropland may cause diffuse nonpoint pollution in the presence of precipitation. Thus, swine production systems which use land application as a manure management strategy should use these BMPs when applying manure to the land.

In addition to federal laws for environmental regulatory activity, the United States Department of Agriculture agencies are providing federal assistance in accordance with overall environmental policy and other procedural directives. In particular, the conservation practice standards by the Natural Resource Conservation Service (NRCS) can be used to address specific waste management needs of swine producers.[13]

An incentive-based environmental subsidy program called the "cost-sharing program" has also been attempted to encourage conservation practices or pollution reduction strategies rather than force polluters to follow a specific rule. This program has been implemented by the Agricultural Stabilization and Conservation Service, a division of the U.S. Department of Agriculture. The cost-sharing program can benefit the swine producers who need to install runoff control systems, manure storage facilities, filter

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[13] Some examples of the USDA NRCS codes are: Waste Management System (Code 312), Waste Storage Structure (Code 213), Waste Treatment Lagoon (Code 359), Waste Storage Pond (Code 425), Waste Utilization (Code 633), and Nutrient Management (Code 590). For a more detailed description about each code, see USDA SCS (1992, pp.1-9 to 1-10).

strips, or other pollution control measures. Cost-sharing is provided by both federal and state governments. Recently, the Federal Agricultural Improvement and Reform Act of 1996 (or commonly called the 1996 Farm Bill) specifically addresses the growing problem of animal waste management by a specific designation of funds with the newly established *Environmental Quality Incentive Programs* (EQIP) (Sanders, 1997; USDA, 1997). EQIP replaces the previous cost-share programs of NRCS. It provides a voluntary conservation program for agricultural producers who pose serious threats to soil, water, and other natural resources. Under EQIP, individual swine producers voluntarily agree to implement BMPs. The major content of the EQIP regarding swine waste management for this study will be more discussed in the state level.

3.3.2. Oklahoma's Environmental Regulations and Programs

Similar to federal environmental regulatory action, the state of Oklahoma has adopted regulations to establish and enforce environmental policies. In 1969 the Oklahoma legislature passed the *Oklahoma Feed Yards Act* (OFYA) in response to the *Water Quality Act* of 1965 which was designed to enhance the quality and value of water resources and to establish a national policy for the prevention, control and abatement of water pollution Gowdy, 1971). Most recently, on May 23, 1997, the Oklahoma legislature passed a new version of environmental regulations on animal feeding operations. The name of the new act was changed from the *Oklahoma Feed Yard Act* to the *Oklahoma Concentrated Animal Feeding Operation Act* (OCAFOA). OCAFOA became effective September 1, 1997. The purpose of this act is "to provide for environmentally responsible construction and expansion of animal feeding operations and to protect the safety, welfare and quality of life of persons who live in the vicinity of an animal feeding operation" (Amending 2 Oklahoma Statutes (hereafter called O.S.), Section 9-201-(B)). The main features of the new act include modification and addition of definitions, clarification and updating of certain terminology, provision for promulgation of rules which require waste management practice plan, certain minimum distance for separation, standards for designing waste retention structures, and the increased license issuance fee. In this act, a concentrated animal feeding operation (CAFO) is defined as a licensed managed feeding operation (LMFO) or an animal feeding operation which has more than 2,500 swine each weighing over 55 pounds where pollutants are discharged into waters of the state or more than 750 swine where pollutants are discharged into waters of the state through an artificially constructed ditch, flushing system or other similar artificially constructed device (O.S., Section 9-202-(B)-(11)).

The OCAFOA of 1997 provides for new rules for an animal production site. The rules require minimum setback distances between dwellings and water wells for new swine facilities. The regulatory framework of OCAFOA uses technology-based standards as environmental policy tools. Swine producers as a CAFO are required to obtain a license, follow a set of guidelines, and formulate a waste management plan. License costs and annual renewal range from $15 with 625 head to $225 with over 25,000 head of swine feeding operation based on one-time capacity. Violations of any rule adopted by the Board to prevent water pollution from the animal operation may be punished by fines varying from $500 to $10,000 for each violation, by imprisonment in the county jail for not more than six months for each violation, or by the assessment of an administrative penalty of up to $10,000 for each violation (O.S., Section 9-212-(B)).

The regulatory rules for storage structures and land application of swine waste should be considered when evaluating various waste management systems. The requirements for waste storage facilities and waste application in this act are provided as follows (O.S., Section 9-(C)):

> *(1) Land application of animal waste shall not exceed the nitrogen uptake of the crop coverage or planned crop planting with any land application of wastewater or manure. Where local water quality is threatened by phosphorus, in no case shall the applicant or license exceed the application rates in the most current Natural Resources Conservation publication titled Waste Utilization Standard, and*
> *(2) Timing and rate of application shall be in response to crop needs, expected precipitation and soil conditions;*
> *(3) Land application practices shall be managed so as to reduce or minimize the discharge of process water or animal waste to waters of the state, contamination of waters of the state, and odor.*
> *(4) Facilities including waste retention structures, waste storage sites, ponds, pipes, ditches, pumps, diversion and irrigation equipment shall be maintained to ensure to fully comply with the terms of the OCAFOA, and*
> *(5) Adequate equipment and land application area shall be available for removal of such waste and wastewater as required to maintain the proper operating volume of the retention structure.*

Currently, the environmental regulations on swine waste management in the OCAFOA could be summarized as license requirement by animal size, time and rate of manure application, land application practices, storage size, and minimum distance separated from the waste disposal site. In order to analyze a more comprehensive regulatory framework, possible regulations could be formulated as animal density constraint based on animal-land ratio in Indiana state and as covering all outdoor waste storage facilities in Iowa state.[14] In evaluating various swine waste management systems, possible environmental regulations will be considered in the sensitivity analysis.

As mentioned above, the federal environmental program of the Environmental Quality Incentive Program (EQIP) has also been recently administered by the Oklahoma NRCS. The first Oklahoma sign up with the new EQIP rules was conducted during late May through June 6, 1997 (Sanders, 1997). EQIP provides technical, financial, and educational assistance primarily in designated priority areas with a special environmental sensitivity.

Currently, Oklahoma has 8 conservation priority areas, covering most of the state.[15] Study areas in this study include the High Plains in Texas county and the Southeast Environmental Concerns in Seminole county. Environmental concerns in each study region include adequate livestock water in High Plains and build-up of soil phosphorus levels, leaching and runoff from animal waste disposal in Southeast Environmental Concerns. In 1997, Oklahoma has $4.3 million allocated for EQIP for one year, with about two-thirds of that estimated to target livestock concerns. Funding comes from federal government's Commodity Credit Cooperation. The NRCS may pay up to 75 percent of the cost of approved conservation practices for facilities for animal waste

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[14] The Indiana Confined Feeding Control Law (1996) states that sufficient acreage must be available for spreading the manure for the swine operation. The annual animal capacity per acre is 17 head with a liquid storage system and 65 heads with a lagoon system (Indiana Department of Environmental Management, 1996). The regulation on covering all outdoor manure storage facilities in Iowa state was analyzed by Babcock, Fleming, and Bundy (1997).

[15] Oklahoma NRCS approved 8 conservation priority areas such as High Plains (10 counties), Wheat belt (11 counties), Eucha-Illinois Systems (4 counties), Southeast Environmental Concerns (11 counties), Washita (5 counties), Deep Fork (8 counties), Big Pasture (5 counties) and Southwest Great Plains (4 counties).

management, as shown in Table 3-2. In the EQIP, an animal waste management facility includes waste storage structures (slurry tanks or pits), waste treatment lagoons, oxidation ditches, and collection equipments (USDA NRCS OK, June 1997b). Incentive payments may also be made to encourage conservation practices such as nutrient management, waste management, and irrigation water. The total of both cost-share and incentive

Table 3-2 Swine Producers' Eligible for Cost-sharing Rate and Incentive Payment in the Environmental Quality Incentive Program

Eligible Practices	Unit	Cost Share Rate	Average Cost	Incentive Payment Level
		--- percent---	--- dollar--	----- dollar---
Waste Storage Facilities				
Waste Storage Facilities	no.	75	-	-
Waste treatment lagoon	no.	75	-	-
Covered anaerobic lagoon	no.	75	-	-
- excavation and/or embankment	cu.yd.	75	0.94	-
- clay liner	cu.yd.	75	1.25	-
Fence	ft.	75	-	-
Pipeline	ft.	75	-	-
Pond	no.	75	-	-
Bentonite Sealant	no.	75	-	-
Well	no.	75	-	-
Waste Application				
Water spreading	acre	75	-	-
Waste utilization	acre	-	-	2.00
Cover and green manure crop	acre	-	-	10.00
Nutrient management (cropland)	acre	-	-	2.00
(grazing land)	acre	-	-	0.50
Irrigation systems				
- Sprinkler	no.& acre	75	-	-
- Pipeline: underground, plastic	ft.	75	-	-

Source: USDA, NRCS Oklahoma (May, 1997b) payments is limited to $10,000 per person per year and $50,000 for the 5-10 year contract. Eligibility is limited to persons who are engaged in crop or animal production. Eligible land includes cropland, rangeland, pasture, and other ranch land where the program is delivered. Swine producers with 1,000 animal units (i.e, 6,700 head finishing pig of 150 pound) or less are eligible for assistance for animal waste management facilities. However, large confined livestock operations with more than 1,000 animal units are not eligible cost-sharing assistance. These operations may receive technical, educational, and for financial assistance. To estimate the effects of environmental programs on the swine production and waste management, the cost-sharing rate with different size of operations will be considered in this study.

3.4 Description of Major Swine Waste Management Systems

3.4.1. Components of a Swine Waste Management System

The swine waste management system is an integral part of a well-planned swine feeding operation. Swine waste should be managed so that it does not degrade air, soil, and water resources.[16] The six major components are waste production, collection, storage, treatment, transfer, and utilization (USDA SCS, 1992), as presented in Table 3-3. The waste generated from swine production include manure, water, and bedding material. The collection phase is the accumulation of the waste into a gutter, a pit, or a wet well.[17]

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16 A system is a collection of components arranged and interconnected in such a way that when changes occur in one component, the effects of the change may be felt by the other components as well. The definition of a waste management system is drawn from USDA, NRCS, Code 312 (1995).

17 An animal waste management plan should identify the method of collection, location of collection points, scheduling of the collection, labor requirement, necessary equipment or structural facilities, management and installation costs of the components, and the impacts that collection has on the consistency of the waste

Waste may be collected by slotted floors scraping, or by flushing.[18] The waste must then be transported from the collection points to a storage facilities. Waste may be transferred

Table 3-3 Components of Swine Waste Management Systems

Category	Functional Contents	Alternative Sub-system
Production	· Amount and nature of swine waste generated by a swine enterprise · Affecting the consistency of waste	
Collection	· Initial capturing and gathering of the waste from swine building or deposition to collection points	· Slotted flooring systems · Scraping system · Flushing systems
Storage	· Intermittent holding of the waste · Providing flexibility for scheduling and timing of the system	· Above or below ground tank · Earthen cement or steel structures
Treatment	· Reducing the pollution potential of the waste through biological, physical and chemical processes	· Lagoon systems · Composting · Oxidation ditches
	· Including pre-treatment with liquid/solid separation	· Mechanical separation · Settling basins
Transfer	· Movement and transportation of the waste throughout the system	· Pipeline by gravity · Pumping systems · Tank wagon
Utilization	· Recycling reusable waste material · Land application of waste as plant nutrient resources	· Hauling system · Irrigation system

Source: USDA SCS (1992) and MWPS (1993).

(USDA SCS, 1992, p.9-3).

[18] As a modification of a flush system, pit recharge uses a valve which is opened, draining the manure out of the pit, approximately once a week. Immediately after the pit is empty, the valve is closed and about 12 inches of treatment lagoon water is added back into the pit.

to storage through gutters by gravity, a large piston pump, or hauling equipment. Swine waste must generally be stored because waste generation is continuous while the times of application are discontinuous. Common storage facilities include storage tanks and earthen structures. A treatment process may be used to reduce, stabilize, concentrate, or separate nutrients or organic matter in the waste stream. A reduction in the nutrient content of the stored waste reduces the land waste reduces the land area necessary to utilize the waste. A producer with a limited land available on which to apply the waste may want to reduce the nutrient in swine waste. Treatment systems include lagoons, oxidation ditches, settling basins, mechanical separators, anaerobic digesters, and composting. Once the stored swine waste has been treated, the waste must be transported to its final destination. The waste can be transported to the land application area by truck, tank wagon, or by pumping the waste through irrigation pipes. Then, swine wastes are incorporated into the soli for recycling.

Alternative waste management systems are created when any of the six components of the waste handling system are modified or replaced with another. The common waste handling systems such as waste storage and application systems are discussed below.

3.4.2. Waste Storage Systems

Swine waste in a liquid or slurry form can be stored in an outside storage tank, an underfloor pit, an outside earthen pit, or in a lagoon. Outside waste storage tanks can be constructed above ground from concrete or steel or below ground from concrete on earth.

Waste removed from the building as a slurry and stored outside assists in removing odors. As shown in Table 3-4, the covered above ground slurry tank has a high retention of nitrogen nutrients and very low potential for causing problems with water and air quality.

Table 3-4 Nitrogen Loss and Environmental Quality Impact of Waste Storage Systems

Classification of System	Nitrogen Loss	Water quality[a)]	Air quality[b)]
	--percent--		
Underfloor storage pit (concrete bottom)	15-30	very low	medium
Above ground tank (concrete or tank)			
· covered, no leaks	5-10	very low	very low
· not covered, no leaks	10-20	very low	medium
· not covered, leaks	15-25	very high	medium
Below ground tank (concrete)			
· covered, no leaks	5-10	very low	very low
· not covered, no leaks	10-15	very low	medium
· not covered, leaks	10-20	very high	medium
Earthen			
· not covered-clay liner, clay soil	70-85	very low	high
· covered-clay liner, clay soils	50-60	very low	low
· covered-clay or synthetic liner, clay soils	50-60	medium	low
· no liner, clay soils	60-70	medium	high
· no liner, sandy soils	60-70	very high	high

a) For water quality in a storage system, relative impacts are based on the stored manure's potential contact with soil or surface waters. All storage capacities are assumed to be adequate for at least six months. The storage location is assumed to be at least 300 feet from a well or surface water and six feet above the water table.

b) For air quality in the storage system, the environmental impact is based primarily on the ratio of surface area to volume. Larger surface areas are at higher impact for producing odors or gases.

Sources: The loss of nitrogen is drawn from MWPS (1993) and Sutton, et al. (1996), and the environmental quality impacts is from Schmidt and Jacobson (1994).

However, the slurry tank system is expensive construction cost and requires more land for disposal due to the high retention of nutrients. In addition, more labor is required to periodically remove waste from the tank due to limited tank capacity.

An underfloor pit system combines the phases of collection, transfer, and storage of waste handling. This early system was used with slotted floors and provides easy collection of liquid waste and slurry (USDA SCS, 1992; MWPS, 1993).[19] The waste storage pit has a relatively low nitrogen loss and minimizes the possibility of water pollution, as shown in Table 3-4. However, underfloor storage systems generally have higher investment costs than other waste storage system due to a high construction cost. The main problems are with odors and gases. Well-designed ventilation systems which incorporate underfloor pit ventilation help reduce inside odor problems with these system but the release of gases associated with manure removal limits their use.

An outside earthen pit, unlike an underfloor pit, does have distinct collection, transfer and storage phrases of waste management. This system could be a viable alternative when space, topography or soil structure becomes a restrictive factor in a storage site (MWPS, 1993). This system provides a temporary holding area and does not treat the waste. The size of outside earthen pits depends on storage period, manure generation, flush water, and added volume for safety factors. Solid waste should not be

[19] Swine waste stored in pits usually contains 4 to 8 percent solids and is considered a slurry. Slurries containing up to 15 percent solids can be pumped with special equipment. Solids will settle during storage and thorough agitation is required before pumping.

trapped, thus the volatile solids loading rate is not applicable (USDA SCS, 1992).[20]

Lagoons are a lined earthen basin which provide a useful method of treating swine waste and of storing treated waste material until final use, generally application to soil for recycling into crop production (Hamilton, 1997c). According to the mode of degradation, waste stabilization ponds are classified as anaerobic, facultative, or aerobic system. Anaerobic lagoons are the most common and practical for swine waste handling because they have lower operating costs and allows land application of the effluent by an existing irrigation system (North Carolina Cooperative Extension Service, 1997). However, even a properly functioning anaerobic lagoon can produce nuisance odors and a need for periodic sludge removal. In the lagoon systems, there are significant losses of nitrogen to the atmosphere from bacterial action, as shown in Table 3-4. In general, lagoons are designed to store sludge for 10 to 20 years, but there is a definite limit to how much sludge a lagoon can contain. Lagoons are also designed to hold rainfall and runoff from extreme storm events. In areas where water conservation is a concern, recirculated lagoon water can be used to dilute the waste and flush it into an earthen lagoon. The advantages of using recycled water include: decreased demand on the domestic water supply and less hydraulic loading on the lagoon. The disadvantages of using recycled water include an addition cost for recycled pumping, limited supply of irrigation water, or potential disease problems.

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[20] The volatile solid loading rate represent the amount of solid material in wastes that will decompose as opposed to the mineral fraction. The rate which depends on the temperature is an important factor in designing anaerobic lagoon system (USDA SCS, 1992, p.10-27).

3.4.3 Waste Application Systems

The land application method should be based on the type and consistency of the waste available, feeding management, individual producer's resource endowment and preferences. The travel distance, application rate, and equipment cost must be considered when establishing the swine waste management plan. Waste application methods include purchased equipment to haul, to pump or hiring of a custom applicator.

Waste hauling requires the transfer of waste from storage to a tank which is hauled or driven to the field where the waste is applied. All consistencies of waste streams can be hauled. Waste spreaders are used primarily for solid and semi-solid waste while tank wagons (commonly called a "honey wagon") and tank trucks are used for slurry and liquid wastes. As shown in Table 3-5, the hauling system using surface broadcast permits disposing manure at a relatively low financial cost, but has hidden environmental costs including soil compaction and loss of nitrogen. Injector knives can be added to liquid and slurry spreaders for subsurface injection where odors are a problem or where maximum nutrient retention is required.

Irrigation methods are gaining popularity with liquid wastes because of problems with labor, storage, field accessibility, compaction and limited times for hauling. Irrigation can be by sprinkler, traveling gun, or gated pipe. The type of irrigation system depends upon the consistency of the waste stream. Most irrigation systems can handle liquid waste with up to 4 percent solids, which is typical effluent from a lagoon (MWPS, 1993). Waste from handling systems which use lots of dilution water or where liquid-solid separation is used is an appropriate for application by irrigation. Swine slurries can also be applied using special pumping equipment and through sprinklers with large nozzles (1" nozzle or larger). Irrigation systems can deliver large volumes of liquid in a timely manner, but these advantages must be balanced against odor nuisance, high ammonium nitrogen losses, and susceptibility to wind drift (Brodie, 1994). Properly designed irrigation systems allow uniform application of wastewater at agronomic rates without direct runoff from the site. The two primary types of wastewater irrigation systems are

Table 3-5 Nitrogen Loss and Environmental Quality Impact of Waste Application Systems

Classification of System	Nitrogen loss[a]	Water quality[b]	Air quality[c]	Soil compaction	Timeliness
	--percent--				
Hauling Methods					
Injection	0- 3	very low	very low	poor	fair
Surface broadcast					
· incorporation	1- 5	medium	high	good	fair
· no incorporation	10-25	very high	very high	poor	fair
Pumping Methods					
Sprinkler (center pivot)	20-30	medium	very high	excellent	excellent
Big gun	30-40	medium	very high	excellent	excellent
Time of Application					
Spring	high	very low	low	-	-
Fall or Winter	low	medium	very low	-	-
Summer	high	very low	very high	-	-

a) Percent of total nitrogen lost within 4 days of application.
b) The water quality impact is based on the potential for over application.
c) The air quality impact is based primarily on manure's exposure to air.
Source: The loss of nitrogen is drawn from Sutton, et al. (1996), and the environmental quality impacts from Schmidt and Jacobson (1994). The evaluation of soil compaction and timeliness are drawn from Koelsch (1995).

stationary and traveling sprinklers. The main advantage of the stationary sprinkler system is with irregularly shaped fields. Traveling sprinkler systems include cable-tow traveler, hard-hose traveler, center pivot, or linear-move systems (Solomon, 1988; Brodie, 1994). The use of center-pivot systems is increasing and they are available in both fixed-pivot point and towable systems.

Custom applicators typically use large truck-mounted tanks with high volume vacuum agitation pumps. Custom application has the potential problem of custom applicator not being available at precisely the time that the waste needs to be hauled. However, this may be offset by the benefit of having good waste handling equipment available without the high investment and operating expenses involved in owning equipment that is used only a few days a year. While the rate charged by custom applicators varies with location, charges are usually about equal to the value of the nitrogen, phosphorus, and potassium fertilizer nutrient value contained in the waste (MWPS, 1993).

When transporting wastes to a field using any waste application system, special consideration should be given to soil and climate characteristics that limit the opportunity for waste application. With twelve-month storage systems, all the waste stored or treated could be spread prior to plowing, or injected after planting, allowing for maximum plant nutrient uptake. Timeliness is related to the limited times of opportunity in the application systems to meet crop nutrient needs to minimize nutrient loss. In practice, the ability to move large quantities of swine waste during short time periods is critical. Table 3-5 also provides the degree of timeliness in each application system. Generally, irrigation systems enhance timeliness in waste application. Seasonal factors are important because of environmental concerns. Nitrogen loss as ammonia from land is greater during spring or summer months than fall or winter months. Usually, late fall or winter applications may have less nuisance odors and greater labor availability (MWPS, 1993).

CHAPTER IV

FRAMEWORK OF INTEGRATED DECISION MODEL

In this chapter, an integrated decision model for selecting the most profitable swine waste management system is explained using a mathematical programming. Economic engineering and mixed integer programming approaches are provided and justified as major analytical tools for determining and comparing the costs of alternative swine waste management systems. The theoretical basis of a mixed integer linear programming (MILP) model with binary variables is briefly explained. An overview of solving algorithms and interpretation of shadow prices in MILP is provided.

4.1. Conceptual Framework of Integrated Decision Model

The economic analysis of alternative swine waste management system involves several steps: defining the objectives, formulating assumptions, generating alternatives, determining costs and benefits, performing sensitivity analysis and ranking alternatives.[21] Figure 4-1 depicts an integrated decision model as a sequential process with feedback providing the sensitivity analysis to reiterate the economic analysis process. What follows is a brief explanation of each step in the sequential process for selecting an optimal swine waste management systems.

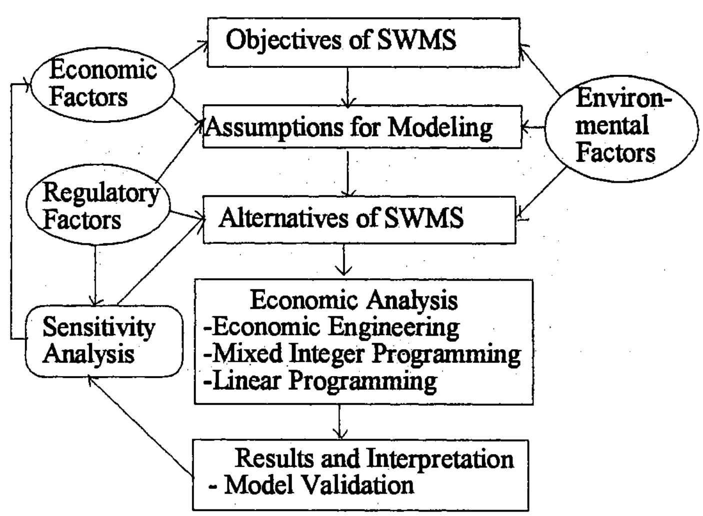
The initial step in the economic analysis is to determine the objective of a swine waste management activity. The objectives include the following: 1) maximizing profit

[21] For a more detailed discussion of systematic approach to economic analysis, see Naval Facilities Engineering Command (1993), p.2.1~2.15.

from swine production and benefits of waste utilization; 2) minimizing resource requirements in land, labor, or capital, and; 3) meeting environmental regulations on concentrated swine feeding operations. The relative importance of the objectives will vary with different swine complexes, depending on the specific needs and restrictions of the swine feeding operations. The optimal system based on a producer's overall profitability incorporates all these objectives within a given set of constraints.

After establishing a set of objectives, the next step is to identify feasible waste management systems which are capable of meeting the objectives and constraints. The swine waste management plan is a specific combination of environmental factors (e.g., rainfall, evaporation, temperature, topography, soil type, and water table depth), regulatory factors (e.g., federal and state environmental regulations), and economic factors (e.g., availability of land and labor, size of operation, and existing equipment and

Figure 4-1 Integrated Decision Model for Selecting Optimal Waste Management System



facilities).[22] A swine waste management system includes six components of production, collection, transfer, storage, treatment, and utilization of swine waste (Refer to Table 3-3).

Determining costs and benefits of handling swine waste are basic criteria for evaluating alternative waste management systems. In practice, explicit costs and their components are easier to identify than their benefit counterparts because most of the equipment and facilities used to handle swine waste are traded in conventional markets. So, an overall profitability based on the cost assessment will be used for the criteria in evaluating alternative swine waste management systems. In formulating the methodological basis for estimating the costs of alternative waste management systems, an economic engineering approach will be employed.[23]

The economic engineering approach is similar to a budgeting method. The budgeting is defined as "the orderly presentation of the anticipated results of a plan, project, or strategy" (Sweeny and Rachlin, 1981). Budgeting can also be used for assistance in allocating resources, the ability to control swine pollution and to predict performance of an alternative waste management system. The economic engineering approach to cost assessment relies upon the knowledge base of experts in abatement technology for controlling swine pollution problems. Analysts (engineers, animal scientists, and agronomists) are called upon to identify the combinations of equipment, labor, and materials needed to construct a system to comply with environmental

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22 The factors affecting swine waste management system were discussed by USDA SCS (1992), Sutton, Foster, Underdown, Jones, and Sutton (1993), and Hamilton (1997a).

23 For a more detailed description about the economic engineering approach, see Tietenberg (1992), pp. 84-86.

regulations. Then capital and operating costs for each feasible system are estimated.[24] Capital costs are the fixed investment expenditures necessary to construct the waste handling facilities and purchase the necessary equipment. Operating or variable costs incurred in the operation and maintenance of a waste management system include those for materials, equipment leasing, repairs, supplies, direct labor, fuel and power.

Comparing overall profitability is an essential step of justification in selecting the optimal waste management system because it provides for a better management decision-making strategy in swine production and waste management planning. Basically, planning problems in selecting optimal swine waste management system involve "discrete" cost or "lumpy" (use of integral units) supplies of inputs. The introduction of an integer decision variable in the model formulation allows for a better description of system analysis comprising units of equipment and facilities which are of an integer nature, and other decision variables expressed in continuous terms. In particular, the binary variables with 0-1 enable us to solve "either-or" problems describing real swine waste management systems within a given set of constraints. Thus, in order to meet the objectives in this study, the analytical method is based on the 0-1 mixed integer linear programming (MILP) model which allows one to depict discontinuous decision variables such as machines or equipments.

Finally, in order to improve model performance and problem insight, model validation is required. Model validation means the process of determining acceptability of

[24] The distinction between capital and operating costs is in the relationship between levels of cost and the quantity of pollution abatement. A capital cost is incurred regardless of the amount of pollution abated while operating costs are directly related to the quantity of pollution abatement.

a model for its intended purposes.[25] In particular, a validation procedure is an important concern within the context of a mathematical programming analysis since model solution could be compared with corresponding real world outcomes. In addition, performing sensitivity analysis is necessary to test influences on the sensitivity of analytical results because uncertainties are always present in selecting the most profitable waste management system. This analysis provides feedback within the economic analysis process by indicating that alternatives, estimates and assumptions are in need of further refinement. If a change in a parameter or an assumption in designing a waste management system results in a significant change in the results, then the results are sensitive to that parameter or assumption. Mathematical programming analysis including an MILP is not only interested in an optimal solution but also in the results of a sensitivity analysis of a model.

The sequential process mentioned provides a comprehensive framework for economic analysis of swine waste management systems. In reality, a swine producer's decision making process in choosing the optimal waste management system is more complex due to existence of the many identified factors. Storage capacity and equipment methods in handling swine waste involve interdependent decisions which imply a simultaneous consideration of all factors in the system (Hamilton, 1997a). A system approach for this complex problem will be based on the integrated decision model, which

[25] Approaches to validation vary widely according types of mathematical programming models such as prescriptive and predictive models. Detailed procedures were outlined for validating aspects of model performance by McCarl and Apland (1986) and McCarl and Spreen (1996).

includes all the factors in the system Thus, the integrated decision model developed in this study allows for suggesting to the swine producer the most profitable waste management system from numerous feasible systems and for analyzing economic effects of the selected system to meet environmental regulations and resource constraints.

4.2. Mathematical Description of Mixed Integer Linear Programming

The general formulation of a mixed integer linear programming problem (v_{MILP}) containing 0-1 variables is mathematically stated as (Nemhauser and Wolsey, 1988):

$$v_{MILP}(c,h,A,G,b) = \max \left\{ c'x + h'y \mid Ax + Gy \leq b,\ x \in \mathbb{R}^n_+,\ y \in \{0,\ 1\}^p \right\}. \qquad (4\text{-}1)$$

where x is a vector of continuous variables which is the set of nonnegative integrating n-dimensional vectors, y is binary variables with p-dimensional vectors,[26] c' and h' are ($n\times1$) and ($p\times1$) vectors of parameters, A and G are matrices of appropriate dimension, and b is a vector of m.

The MILP in (4-1) has a linear objective function and linear constraints in x and y. The name of this MILP is drawn from the presence of a mixed set of variables (i.e., continuous x and binary y variables). Theoretically, the MILP problem can be solved if the required data (c, h, A, G, b) are adequately specified and collected. The feasible region is defined as the set $S = \{x \in \mathbb{R}_+^n,\ y \in \{0,1\}^p,\ Ax + Gy \leq b\}$ and the feasible solution is given by $(x, y) \in S$. A specified problem is said to be feasible if $S \neq \emptyset$. The

---

[26] The decision variable y represents the binary state of alternative systems, i.e., $y_i = 1$ if the system is effective and $y_i = 0$ otherwise, where I = 1,2,...,p.

function z = c'x + h'y is called the objective function. A feasible point (x^*, y^*) for which an objective function value is as large as possible is called an optimal solution, that is, $c'x^* + h'y^* \geq c'x + h'y$, $\forall$ (x, y) $\in$ S. According to an analytical objective, the binary variable associated with multiple alternatives can be formulated as follows (Floudas, 1995):

$$\begin{aligned} &\sum_{i \in P} y_i = 1 \quad : \quad \textit{Select only one system}, \\ &\sum_{i \in P} y_i \leq 1 \quad : \quad \textit{Select at most one system, and} \\ &\sum_{i \in P} y_i \geq 1 \quad : \quad \textit{Select at least one system}. \end{aligned} \tag{4-2}$$

Note that integer and linear programming models can be explained by delineating special cases of the MILP problems. The MILP model in (4-1) becomes a pure integer programming problem (v_{PIP}) if the x values are non existent.

$$v_{PIP}(h, G, b) = \max \left\{ h'y \mid Gy \leq b,\ y \in \{0,\ 1\}^p \right\}. \tag{4-3}$$

Similarly, if the vector h' and the matrix G have all elements zero, then (4-1) becomes a linear programming problem (v_{LP}).

$$v_{LP}(c, A, b) = \max \left\{ c'x \mid Ax \leq b,\ x \in \mathbb{R}^n_+ \right\}. \tag{4-4}$$

Conceptually, any choice of 0 or 1 for the elements of the vector y results in an LP problem in (4-4) on the x variables which can be solved for its optimal solution. However, the major difficulty in the MILP problem in (4-1) arises from the combinatorial nature of the y variables. For instance, if ten 0-1 y variables were used, then 2^{10} combinations of 0-1 cases are possible. Such an all enumeration approach grows exponentially in time with respect to its computational effort. In the literature, several different algorithmic approaches such as branch and bound methods, cutting plane methods, decomposition methods, and logic-based methods have been proposed despite the difficulty of the combinatorial nature of an MILP model (Williams, 1996).

4.3. Branch and Bound Algorithm for Solving MILP Problems

Branch and bound methods are the most commonly used algorithms in large-scale mixed integer programming. The main objective of the branch and bound method which was pioneered by Land and Doig (1960), is to enumerate the alternatives without examining all possible 0-1 combinations of the y-variables. It is convenient to represent this method diagrammatically using a binary tree structure as illustrated in Figure 4-2. For simplicity of description, consider the three levels of the binary tree. Each level has a number of nodes and there exists a specific connection between nodes of succeeding levels via arcs. Using the concept of an LP relaxation of the MILP by dropping the integer restrictions, the branch and bound approach can be explained combined with the binary tree (Floudas, 1995). At level 0, there is one node which is called the root node. The node at the level 0 corresponds to the set of all feasible solutions. In the root node of a binary tree, the LP relaxation at the level 0 (v_{LP}^0) of the MILP model of (4-1) takes the following form:

$$v_{LP}^{0} = \max \left\{ c'x + h'y \mid Ax + Gy \leq b,\ x \in \mathbb{R}_{+}^{n},\ y \in [0,\ 1]^{p} \right\}. \qquad (4\text{-}5)$$

That is, all binary y-variables in (4-5) have been relaxed to continuous variables with lower and upper bounds of zero and one, respectively.

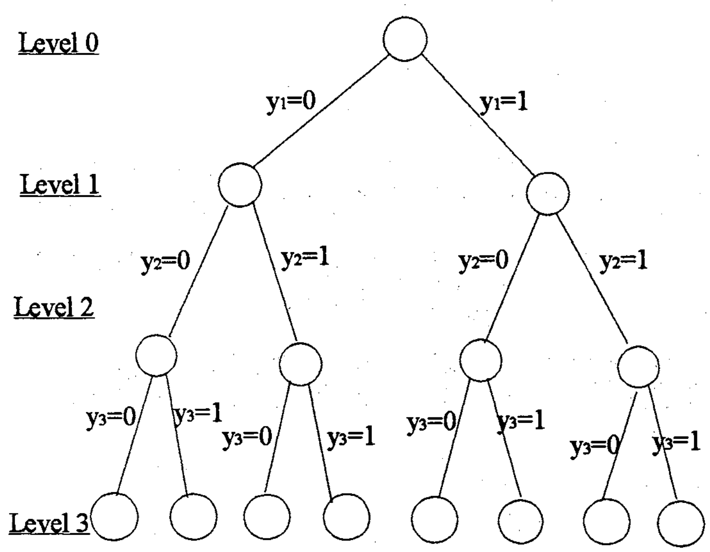
At the subsequent level 1, there are two nodes and the branching is based on setting y_1=0 for the one node and y_1=1 for the second node, as shown in Figure 4-2. The root node is the parent node for the two nodes of level 1, and thus there are two candidate sub-problems at this level. So, the LP relaxation of the candidate sub-problem will have only a subset of the y-variables set to zero or one while the rest of the y-variables will be treated as continuous variables with bounds between zero and one (Floudas, 1995). That is, the LP relaxation at the level 1 (v_{LP}^1) is given by:

$$v_{LP}^1 = \max \left\{ c'x + h'y \mid Ax + Gy \leq b,\ x \in \mathbb{R}_+^n,\ y_1 = 0,\ y_2 \in [0,\ 1] \right\}. \qquad (4\text{-}6)$$

The solution of an LP relaxation in (4-6) is an upper bound since it has a fixed $y_1 = 0$.

Similarly, at the level 2, there are four nodes and the branching is based on the y_2

Figure 4-2 Binary Tree Structure of Branch and Bound Algorithm



variable. Likewise the LP relaxation at level 2 of the binary tree which has four candidate sub-problems will feature y_1 and y_2 fixed to either zero to one values while the y_3 variable will be treated as continuous with bounds of zero and one. In sequence, there are eight nodes and branching at level 3 is based on the y_2 variable. Each node of level 2 is the parent node of two children nodes of level 3. A number of candidate sub-problems have been generated at each level as a result of this binary tree representation. Namely, two at level 1, four at level 2, and eight at level 3. The feasible region is partitioned into sub-domains systematically, and valid upper and lower bounds are generated at different levels of the binary tree. Fathoming test are employed to avoid the enumeration of all candidate sub-problems. This allow us to eliminate from further consideration not only nodes of the binary tree but also branches of the tree which correspond to their children nodes (Floudas, 1995; Williams, 1996). More detailed procedures of general branch and bound algorithm consist of six steps such as initialization, termination, selection of candidate subproblem, relaxation, fathoming, and separation, as summarized in Table 4-1. In this procedure, the choice of variable upon which we branch at a particular level has been shown to be very important from the computational viewpoint since robust methods for selecting the branching variables are not available. One frequently used way of generating a separation in an MILP problem is by using a generalized upper bound constraint, set the summation equal to one and use mutually exclusive solutions, i.e., $\sum_{I\in s} y_i = 1$ (Floudas, 1995).[27] Often the branch and bound algorithm will come up with near optimal solutions

[27] As an example of a generalized upper bound constraint, if an MILP model includes three kinds of multiple choice constraint, then the constraint is given as: $y_1 + y_2 + y_3 = 1$. So, a candidate sub-problem can be separated into two sub-problems by branching on the variables y1 and y2 and y3: that is, by indicating y_1 +

quickly but will then spend a lot of time verifying optimality. As a solver of the MILP problem, the GAMS/ZOOM will be used for this study. The solver ZOOM is based on

Table 4-1 Procedures for General Branch and Bound Algorithm

Step 1 - Initialization	Initialize the list of candidate sub-problems to consist of the MILP alone using generalized upper bound constraint.
Step 2 - Termination	Terminate with optimal solution the current candidate considered if the list of candidate sub-problem is empty. If a current feasible candidate does not exist, then the MILP problem is infeasible.
Step 3 - Selection of current candidate sub-problem	Select one of the sub-problems in the candidate list to become the candidate sub-problem
Step 4 - Relaxation	Select a relaxation of the current candidate sub-problem. All binary y-variables are relaxed to continuous variables with lower and upper bounds of zero and one, i.e., $0 \le y \le 1$.
Step 5 - Fathoming	Apply the fathoming criteria: I) If relaxation in step 4 is infeasible, the current candidate sub-problem has no feasible solution. Then, go to Step 2. ii) If the optimal solution in Step 4 is feasible, then it is an optimal solution of current candidate subproblem.
Step 6 - Separation	Separate the current candidate sub-problem and add its children nodes to the list of the candidate sub-problem. Then, go to step 2.

Source: Summarized from Floudas (1995; pp.101-103).

$y_2 = 0$ and $y_3 = 1$ in sub-problem 1 and $y_1 = 1$ and $y_2 + y_3 = 0$ in sub-problem 2.

the branch and bound search with an LP relaxation to find and to verify the optimal solution of an MILP problem. The solution of integer programming problems with GAMS is achieved basically by introducing as a new class of variable declaration statements and by invoking an integer programming solver. The declaration statement identifies selected variables to either be BINARY. In turn, the model is solved by utilizing a solved statement which says "USING MIP" (Brooke, Kendrick, and Meeraus, 1996).

4.4. Shadow Prices in MILP for Managerial Decision

A linear programming or convex programming models have clearly defined duality relationships and interpretation which are derived from the calculus underlying the Kuhn-Tucker theory. These dual models provide a valuation of each constraint of the original model. These valuations are usually known as shadow prices and especially have considerable economic significance. Basically, shadow prices in mathematical programming have been based on the concepts of marginal contribution of a resource to the optimal objective value.[28]

As presented above in formula (4-1), the feasible solution regions of the MILP given by $(x, y) \in \{x \in \mathbb{R}_+^n, y \in \{0,1\}^p, Ax + Gy \leq b\}$ are discontinuous and the objective function $z = c'x + h'y$ is neither concave nor convex when the availability of one or more resources changes. So, the calculus analysis cannot be directly applied to the

[28] The term marginal value arises because these valuations give the marginal rate of increase (or decrease) of the objective function with respect to changes in the right-hand-side values taken one at a time. To an accountant they are known as opportunity costs since they indicate the increase (or decreased) opportunity to make a profit through extra (or fewer) resources. For the economic interpretation of shadow prices in a mixed integer programming model, see Williams (1979).

discontinuous MILP models. Thus, duality concepts are much more complicated in the case of MILP models and shadow prices which have plausible economic interpretation or managerial implication are not a well-defined concept in the context of PIP or MILP (McCarl and Spreen, 1996; Williams, 1996).

The dual information in MILP models is often influenced by constraints which are added during the solution process like a branch and bound algorithm. Most solution approaches involve the addition of constraints to redefine the feasible region so that the integer solutions occur at extreme points. So, many of the shadow prices reported by PIP or MILP solvers are not relevant to the original problem, but rather are relevant to a transformed problem for an algorithm considered. The principal difficulty with these dual prices is that the set of transformation is not unique, so new information drawn is not unique or valid. In this context, shadow prices in an MILP have been considered as a fuzzy topic in the literature (Williams, 1996). Several points on shadow prices in an MILP problem should be carefully interpreted. The shadow prices in an MILP would be as reliable as LP shadow prices if the constraints on the right hand side are changed in a range that does not imply a change in the solution value of an integer variable. In addition, the dual variables from the constraints which involve only continuous variables in the MILP framework would appear to be valid. In another point, an MILP model has is no analogy to the complementary principle of an LP where a constraint always has either zero slack or a zero shadow price. A constraint in an MILP model may have "slack" but not represent a zero shadow price as a free good (McCarl and Spreen, 1996).

Recently, the usefulness of shadow prices in an integer programming framework has been suggested by several authors (Kim and Cho, 1988; Crema,1995). An integer programming problem has a lack of the useful properties of the LP for providing economic and accountancy information. In order to use the concept of shadow prices in a pure integer programming framework, average shadow prices were conceptualized by Kim and Cho (1988) as an indicator of potential profitability of a resource not in a marginal sense but in an average sense. The average shadow price is based neither upon duality theory nor upon marginal analysis. Crema (1995) suggested that average shadow prices can be used in MILP problems and that some of its properties are analogous in LP shadow prices. The shadow price information reported in the GAMS/ZOOM output will be interpreted as a concept of average shadow prices in the MILP model for this study.

CHAPTER V

MODELING PROCEDURES OF THE MIXED INTEGER LINEAR PROGRAMMING

This chapter deals with the modeling procedures of the MILP problem. The objective is to select the optimal production and waste management system subject to environmental regulations and resource constraints. The coefficients for the MILP model will be briefly discussed.

5.1. Configuration of Alternative Waste Management Systems

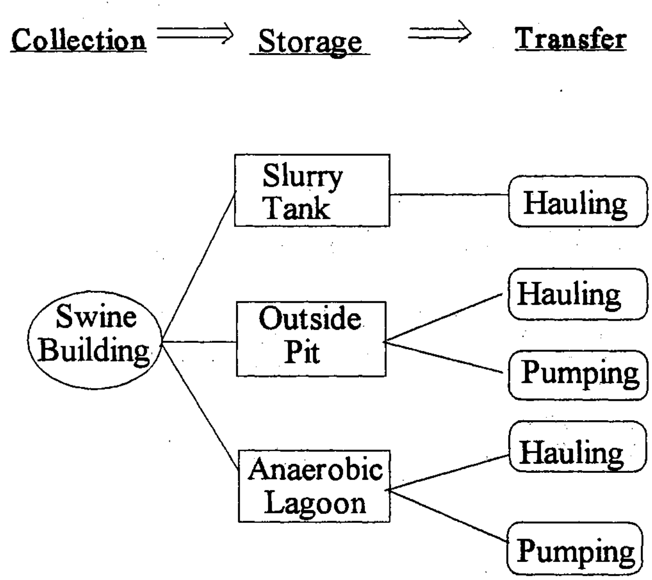
Many swine producers with confined feeding operations handle their animal wastes as a liquid in order to save labor cost. Most swine production operations are a combination of three storage systems (liquid slurry tanks, outside earthen pits, and anaerobic lagoons) and two application systems (hauling and pumping methods), as shown in Figure 5-1. Most recently constructed swine buildings have totally slotted floors. Swine wastes collected under the floor are released by gravity to outside storage structures. Agitation pumps are commonly used for sludge removal and to insure a uniform slurry in storage tank and pit systems. Applying swine waste to land from either of these two systems is typically done using a tank wagon. The waste is injected into the soil or broadcasted over the top soil. Waste may also be applied to the land surface through irrigation systems. Common systems include traveling gun, conventional sprinkler, or center pivot irrigation systems.[29] Lagoon effluent may also be hauled with

[29] The irrigation systems in the study area were pre-screened by personal communication with Hamilton (1997d).

tank wagons or trucks. A feasible waste management system may consist of any one of three storage sub-systems such as slurry tank, outside earthen pit, and anaerobic lagoon. In addition, the feasible alternative waste application systems consist of two sub-systems including hauling and pumping methods.

The overall objective is to determine the optimal size of production facility and type of waste handling facility for a representative producer in the Oklahoma Panhandle and in South Central Oklahoma. However to provide additional information as to how the optimal waste handling systems changes with the size of operation, each waste management system will be synthesized for a 500, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000, 7,000, 8,000, 9,000, and 10,000 head finishing operations. The fifty-five distinct swine waste management systems are possible with eleven herd sizes, three storage

Figure 5-1 Configuration of Alternative Swine Waste Management Systems



systems, and two application systems in each study area.[30]

5.2. Basic Assumptions

Several assumptions are made for analytical convenience and simplicity as follows:

(1) The model is based on the partial and static framework whereas the solution represents returns and the costs for a typical one-year term of a ten year planning horizon.

(2) The representative swine producer operates in a rational manner maximizing profits from the swine production while selecting a waste management system which efficiently meets environmental and institutional constraints. In addition, a producer is assumed to be a price taker in all factors and product markets.

(3) Wheat and corn are major crops used for waste disposal in Texas county. Bermuda grass hay is used in Seminole county.

(4) The production year is divided into 12 monthly periods. The feasible time periods of land application along with the nutrient needs for each crop are presented in Table 5-1.

(5) Producers do not have production and waste management systems, but center pivot irrigation is already in place in the Texas county study area.

(6) All the swine wastes must be disposed of or accounted for in some satisfactory way. The waste management activity is based on the assumption that waste will either be utilized as part of the nutrient management plan, or that custom hauling may be used for excess waste disposal.

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[30] The combination between tank and pumping systems was excluded due to difficulty in reality.

(7) The storage capacity is constant over all time periods and swine waste not used in a given time period is transferred to the next period.

(8) The site chosen for the swine operation has an adequate water supply and is located a sufficient distance from neighbors.

(9) The economic benefit of waste application is confined only to the fertilizer value of the major nutrients, nitrogen and phosphorus, in the manure.

Table 5-1 Feasible Period for Land Application of Swine Waste in Oklahoma

Time	Irrigation Method			Hauling Method		
Period	Corn	Wheat	Bermudagrass	Corn	Wheat	Bermudagrass
January						
February		a				
March	a	a		a		
April	a	a	a	a		a
May						
June	a		a	a		a
July	a					
August	a				a	
September		a			a	
October		a	a		a	a
November						
December						

Note: The application systems are based on the following storage system: irrigation (by center pivot) from lagoon; injection from hauling the tank and pit systems, and surface spreading (by travel gun) from tanks and pit systems. The character *a* represents an effective period of manure application to the field.

Source: The cropping seasons are drawn from *Oklahoma Agricultural Statistics* (Oklahoma Agricultural Statistics Service, 1996) and the distribution of crop nutrient requirement is formulated by communicating with Zhang (1997).

5.3. Formulating the Mixed Integer Linear Programming Model

5.3.1. Calculation of Model Coefficients

Assuming proper constraints and an objective function, the accuracy of the solution to an MILP model depends on the coefficients of the model. Therefore, effort should be taken in deriving them. The following discussion will explain how the needed coefficients were obtained for the integrated decision model.

1) Generation of Swine Manure and Its Nutrients

Once herd size in the model is chosen, it is necessary to estimate the amount of manure generated during a given time period. The generation of swine manure per month can be calculated as follows:

$$MMANGENR(ANIMALNO)_t = \sum_s ANIMALNO_s \cdot MANGENR_s \cdot TIME_t \quad (5\text{-}1)$$

where $MMANGENR(ANIMALNO)_t$ = monthly amount of manure generation during time period t as a function of animal numbers
$ANIMALNO_s$ = number of animal type s
$MANGENR_s$ = daily amount of manure generated in animal type s
$TIME_t$ = length of monthly time period t (30 days)
t = number of time period (12 month period)
s = type of animal operation unit (five types of swine such as nursery, finishing, gestating, sow, and boar)

The amount of each major nutrient generated is given by:

$$MNUTRGR(ANIMALNO)_{nt} = \sum_s ANIMALNO_s \cdot NUTRMAN_{sn} \cdot TIME_t \quad (5\text{-}2)$$

where $MNUTRGR(ANIMALNO)_{nt}$ = monthly amount of nutrient n generated in time period t as a function of animal numbers

$NUTRMAN_{sn}$ = rate of nutrient generation n in animal type s (lb/day)
n = type of nutrients (i.e., nitrogen, phosphorus, and potassium)

2) Capacities of Waste Storage Systems

Once herd size and quantities of manure generation are determined, it is necessary to estimate the capacity of the waste storage facility required. For protection from potential pollutants, the capacity for waste storage should be large enough to contain accumulated waste plus the net additions of waste during each time period. Environmental regulations require that an open storage structure have additional capacity available to hold larger than expected rainfall and runoff. The required capacity of the storage system can be determined as follows:

Storage Tank Systems

$$REQVOLTK(ANIMALNO) \geq \sum_s ANIMALNO_s[MANGENR_s + WWATER_s] \times STORTIME \quad (5\text{-}3)$$

where REQVOLTK(ANIMALNO) = required capacity of outside slurry tank volume as a function of animal numbers
$MANGENR_s$ = rate of manure generation of animal type s
$WWATER_s$ = wastewater generation in animal type s
STORTIME = time period for storage

Outside Pit System

$$REQVOLPIT(ANIMALNO) \geq \sum_s ANIMALNO_s[MANGENR_s + WWATER_s] \times STORTIME + SAFEVOL(ANIMALNO) \quad (5\text{-}4)$$

where REQVOLPIT(ANIMALNO) = required capacity of pit storage volume as a function of animal numbers
$MANGENR_s$ = rate of manure generation of animal type s
$WWATER_s$ = wastewater generation in animal type s
STORTIME = time period for storage
SAFEVOL(ANIMALNO) = safety volume as a function of animal numbers

Lagoon System

The lagoon system in this study is based on a single stage anaerobic lagoon. The maximum operating level of an anaerobic lagoon is a storage volume requirement plus a depth adjustment. The total capacity of an anaerobic lagoon includes the sum of the treatment volume, waste volume, sludge volume, and safety volume. Thus, required volume of an anaerobic lagoon is given by:

$$
\begin{aligned}
&REQVOLLG(ANIMALNO) \\
&\geq [MINTRVOL(ANIMALNO)] + [WASTEVOL(ANIMALNO)] \\
&\quad + [SLUDGEVOL(ANIMALNO)] + [SAFEVOL(ANIMALNO)] \\
&= [(TDVSLOAD(ANIMALNO) \cdot 1000) / VSLDRATE] \\
&\quad + [\sum_s ANIMALNO_s (MANGENR_s + WWATER_s) \times STORTIME] \\
&\quad + [DTSGENR(ANIMALNO) \cdot SLACRATIO \cdot SLACPERIOD \cdot 365] \\
&\quad + [SAFEVOL(ANIMALNO)]
\end{aligned}
\qquad (5\text{-}5)
$$

where REQVOLLG(ANIMALNO) = volume requirement of a lagoon as a function of animal numbers
MINTRVOL(ANIMALNO) = minimum treatment volume for volatile solids as a function of animal numbers
WASTEVOL(ANIMALNO) = waste volume including manure, wastewater, flush water, and dilution water for a lagoon as a function of animal numbers
SLUDGEVOL(ANIMALNO) = sludge volume drawn from total solid as a function of animal numbers

SAFEVOL(ANIMALNO) = safety volume as a function of animal numbers as a function of animal numbers
TDVSLOAD(ANIMALNO) = total daily volatile solids production as a function of animal numbers (lbs/day)
VSLDRATE = volatile solids loading rate (lbs VS/1000 cu.ft.)[31]
DTSGENR(ANIMALNO) = daily total solids generation as a function of animal numbers (lbs/daily)
SLACRATIO = sludge accumulation ratio (cu.ft./lb TS)
SLACPERIOD = sludge accumulation period (years)

The safety volume in (5-5) is determined by the depth adjustment factors which are based on the net precipitation (normal precipitation less evaporation on lagoon surface) and the 25-year, 24-hour precipitation on lagoon surface.

3) Cost Estimation

The economic engineering approach was used to estimate the costs of alternative waste handling systems. The economic engineering approach is primarily concerned with comparing alternative systems based on the economic measure of capital and operating costs. The capital costs associated with a given waste storage and application equipment are the sum of the amortized investment charges (i.e., depreciation and interest) and a certain percentage of initial purchase price as insurance and property tax. The operating costs include charges for repairs and maintenance, energy (fuel and electricity), labor and license fee.

In order to calculate the capital costs of buildings, storage structures, and application equipment, the capital recovery factor (or amortization factor) should be determined. The annual capital cost factor which includes capital recovery cost on

[31] The loading rate of volatile solids differ widely within the United States depending upon the geoclimatic conditions. The anaerobic lagoon loading rate in Oklahoma has been recommended to be 5.3 - 6.0 lb VS/1000 cu.ft. per day (USDA SCS, 1992, 0.10-29).

investment, depreciation, taxes, and insurances is calculated as follows:[32]

$$ACCF = CAPRFAC + TAXINRATE$$

$$where \quad CAPRFAC = \frac{r}{1 - (1+r)^{-k}} \tag{5-6}$$

ACCF = annual capital cost factor
CAPRFAC = capital recovery factor
TAXINRATE = rate of property tax and insurance
r = real interest rate
k = useful life of equipment

Based on a capital recovery factor, the annual capital cost (payment of interest and principle) associated with the swine building, storage structures and equipment establishment can be calculated as follows:

$$ACAPCOST(ANIMALNO)_{ij} = \sum_i \sum_j CONSTCOST(ANIMALNO)_i \cdot ACCF_{STO} + EQUICOST(ANIMAL)_{ij} \cdot ACCF_{EQU} \tag{5-7}$$

where $ACAPCOST(ANIMALNO)_{ij}$ = annual capital costs of storage structure i and application system j as a function of animal numbers
$CONSCOST(ANIMALNO)_i$ = construction cost of storage system i as a function of animal numbers
$ACCF_{STO}$ = annual capital cost factor for storage system
$EQUICOST(ANIMAL)_{ij}$ = investment cost of equipment associated with storage structure i and application method j as a function of animal numbers
$ACCF_{EQU}$ = annual capital cost factor of equipment establishment

The costs for operating the waste management system are determined by summing labor cost, repair and maintenance costs, energy costs, and license fee as follows:

[32] The capital recovery factor represents the amount of money required at the end of each year to pay interest on the unrecovered capital at the designated rate and recover the investment within a specified number of years. For a more detailed description of capital recovery factor, see Boehlje and Eidman (1983).

$$OPERCOST(ANIMALNO)_{ij} = LABCOST(ANIMALNO)_{ij} + ENGCOST(ANIMALNO)_{j} + RMCOST(ANIMALNO)_{ij} + LICENFEE\,(ANIMALNO) \quad (5\text{-}8)$$

where $OPERCOST(ANIMALNO)_{ij}$ = operating cost of storage system i and application system j as a function of animal numbers
$LABCOST(ANIMALNO)_{ij}$ = labor cost in system i and j as a function of animal numbers
$RMCOST(ANIMALNO)_{ij}$ = repair and maintenance cost for each system i and j as a function of animal numbers
$ENGCOST(ANIMALNO)_{ij}$ = cost of energy including electricity or fuel for each storage system i and application method j as a function of animal numbers
LICENFEE (ANIMALNO) = license issuance and renewal fee with size of swine operation

Labor requirements for waste handling system are dependent on the application method used. The two basic methods are hauling and pumping. First, the hauling amount of wastes can be calculated by:

$$HAULAM(ANIMALNO)_{i} = \sum_{t} WASTVOL(ANIMALNO)_{t} \cdot \left[1 - \frac{STORTIME}{360}\right] \cdot APPTIME_{ct} \quad (5\text{-}9)$$

where $HAULAM(ANIMALNO)_{i}$ = annual volume to be hauled with system i as a function of animal numbers
$WASTVOL(ANIMALNO)_{t}$ = waste volume including manure and wastewater in time period t as a function of animal numbers
STORTIME = period of storage time
$APPTIME_{ct}$ = feasible constraint of waste application for crop c in time period t

If the hauling system is used the labor cost associated with the waste management system is given by:

$$LABCOST(ANIMALNO)_{i,j=HAUL} = \left[\frac{HAULAM(ANIMALNO)_i}{WAGONVOL \cdot LOADNO}\right] \cdot UCOST_{HAUL} \quad (5\text{-}10)$$

where $LABCOST(ANIMALNO)_{i,j=HAUL}$ = labor cost of hauling activity with storage system i as a function of anumal numbers

WAGONVOL = transferring volume of wagon

LOADNO = number of loading times of wagon per hour

$UCOST_{HAUL}$ = unit labor cost per hour of hauling by tractor

Then, the labor cost of pumping activity for irrigating wastes is determined by:

$$LABCOST(ANIMALNO)_{i,j=PUMP} = \frac{HAULAM(ANIMALNO)_i}{LABREQ_{IRR}} \cdot UCOST_{LAB} \quad (5\text{-}11)$$

where $LABCOST(ANIMALNO)_{i,j=PUMP}$ = labor cost for irrigating storage system i as a function of animal numbers

$HAULAM(ANIMALNO)_i$ = annual hauling amount of storage system i as a function of animal numbners

$LABREQ_{IRR}$ = labor amount required for operating irrigation system (cu.ft./hour)

$UCOST_{LAB}$ = unit cost of labor (dollar/hour)

The energy costs which consist of fuel cost for pulling travel gun and electricity or fuel costs for pumping wastes from storage structures can be calculated by using the formula of the Brake Horsepower (BHP). The procedure of estimating pumping cost is presented in the Appendix A-5.

The cost of repair and maintenance associated with a storage and application system can be calculated as:

$$\begin{aligned} RMCOST(ANIMALNO)_{ij} = {} & [CONCOST(ANIMALNO)_i \cdot PERCENT_{STO}] \\ & + [EQUICOST(ANIMALNO)_{ij} \cdot PERCENT_{EQU}] \end{aligned} \quad (5\text{-}12)$$

where $RMCOST(ANIMALNO)_{ij}$ = repair and maintenance cost associated with storage structure i and application method j as a function of animal numbers

$CONSCOST(ANIMALNO)i$ = construction cost of storage system i as a function of animal numbers

$PERCENT_{STO}$ = percentage of initial investment cost in storage system

$EQUICOST(ANIMALNO)_{ij}$ = investment cost of equipment associated with storage structure i and application method j as a function of animal numbers

$PERCENT_{EQU}$ = percentage of initial investment cost in waste handling equipment

Finally, the fee for a swine feeding operations license and annual renewal is drawn from the OCAFOA of 1997, as mentioned in Chapter III. The license expense is not great as a percent of the total operating cost of swine waste management although the magnitude of the fee depends on the size of the operation.

4) Nutrient Requirement for Crop Production

The nutrient requirement for crop production depends on the type of crop, soil characteristics, and expected yield. For each crop, an expected yield is identified along with nutrients levels (N and P_2O_5) required to attain this goal. The nutrient requirements of the uptake level may be simulated from the *Erosion Productivity Impact Calculator* (EPIC) model.[33] The EPIC can simulate the relevant biophysical processes simultaneously, as well as realistically, using readily available data such as weather, climates, soils, input levels and management practices. Thus, crop nutrient requirements

[33] Beginning in 1981, the EPIC model was developed by USDA ARS, SCS, ERS scientists to determine the relation between soil erosion and soil productivity throughout the USA. EPIC can be used to evaluate previously untested combinations of soil, climate, and crop management, thereby reducing the amount of site specific research needed to assess improved agricultural technology. For a more detailed description of the EPIC, see Williams, et al. (1989) and Williams, et al. (1990).

($CROPUSE_{cnyt}$) for given expected yield in each time period are determined from the EPIC simulated results.

5.3.2. Decision Variables

The mathematical optimization problem of this study has six decision variables.

First, the variable of waste management system ($SYSTEM_{ij}$) which is a combination of storage structures and application methods is a flagged binary in order to ensure that a whole unit, is in the optimal solution. The variable is bounded to be binary, i.e.,

$$SYSTEM_{ij} = \begin{cases} 1 \text{ if storage system i and application system j is selected to be installed} \\ 0 \text{ otherwise} \end{cases}$$

Second, the variable of nutrient availability ($AVNUTR_n$) generated from swine waste is determined by subtracting nutrient loss in storage and application systems from total amount of waste generated. This decision variable is continuous and bounded to be positive.

Third, the variable of amount of fertilizer ($AMFERT_n$) is determined by the relationship between nutrient requirement for crop production and availability of nutrient generated from swine waste associated with storage and application systems. The nutrient requirement of each crop associated with waste application system was drawn from the EPIC simulation. This variable shows that shortage amount of nutrients drawn from the optimal waste management system. This decision variable is continuous and bounded to be positive.

Fourth, the variable of amount of excess nutrients ($EXNUTR_n$) as a reciprocal variable of fertilizer amount is determined if an application rate of swine waste to cropland is greater than plant nutrient uptake level drawn from the EPIC results. If this variable achieves a positive value, then more land is needed in order to utilize all excess nutrients. Conversely, if the variable takes on a negative value, then there is a shortage of nutrients to meet the needs of the crop grown. This variable is continuous.

Fifth, the variable, additional acres needed ($ADDLAND_{cy}$) associated with crop type and expected yield ability will be determined according to the sign of excess nutrient variable. That is, if the variable, an excess nutrient is positive, then the additional land is necessary for applying all the excess nutrients generated. This variable is continuous and bounded to be positive.

Finally, the decision variable of the objective vlaue (Z) represents the numerical value of the overall profitability to be maximized. The optimal value may be negative or positive.

5.3.3. Objective Function and Constraints

<u>Objective Function</u>

For a given size of swine operation the waste management goal was to maximize available benefits of waste application (or equivalently, to minimize the costs for waste handling) subject to environmental regulations and resource constraints. It could also be stated as minimizing the cost of swine waste handling. Therefore, the objective function may be algebraically stated as follows:

Z = [Net Revenue from Crop Production excluding Fertilizer Costs]
+[Net Revenue from Swine Production excluding Waste Handling Costs]

- [Waste Handling Costs (= Annual Capital Cost + Annual Operating Cost)]
- [Cost of Buying Commercial Fertilizer]
- [Excess Nutrient Disposal Cost Using Custom Hauling]

$$
\begin{aligned}
Max\ Z = & \sum_{c}\sum_{y} NETRCROP_{cy}\cdot ACRENO_{cy} + \sum_{s} ANIMALNO_{s}\cdot NETRSWINE_{s} \\
& - \sum_{i}\sum_{j} [(ACAPCOST(ANIMALNO)_{ij}\cdot SYSTEM_{ij}) \\
& \quad +(OPERCOST(ANIMALNO)_{ij}\cdot SYSTEM_{ij})] \qquad (5\text{-}12) \\
& - \sum_{n} AMFERT(ANIMALNO)_{n}\cdot PRICENP_{n} \\
& - \sum_{y}\sum_{c} ADDLAND(ANIMALNO)_{cy}\cdot CUSTCOST
\end{aligned}
$$

where $NETRCROP_{cy}$ = net revenue from crop production c with expected yield y excluding fertilizer costs

$ACRENO_{cy}$ = acreage number for crop production c with expected yield y

$NETRSWINE_{s}$ = net revenue from swine type s excluding waste handling costs

$CAPCOST(ANIMALNO)_{ij}$ = annual capital costs of storage system i and application system j as a function of animal numbers

$OPERCOST(ANIMALNO)_{ij}$ = operating cost of storage system i and application system j as a function of animal numbers

$AMFERT(ANIMALNO)_{nt}$ = amount of commercial fertilizer n in time period t as a function of animal numbers

$PRICENP_{n}$ = price of commercial fertilizer with nutrient n

$SYSTEM_{ij}$ = combination of storage structure I and application method j with 0-1 integer

$ADDLAND_{cy}$ = additional land for crop c and yield y in applying the excess nutrient as a function of animal numbers

CUSTCOST = cost for excess nutrient disposal using custom hauling[34]

When the model is solved, the system that has the lowest annual cost and does not exceed any of the constraints will be optimal for the particular concentrated swine feeding operation.

---

[34] The environmental regulation on nutrient loading restriction impose an additional cost for excess nutrient disposal if there exist nutrient surplus. There are several methods for excess nutrient disposal such as spreading on neighbor's land, additional rental land, and payement to contractors for custon hauling. This study was used custom hauling cost for exess nutrient disposal. In this study, the cost of custom hauling swine manure used was $0.20/cu.ft. (USDA ERS, 1996).

Constraints

The swine waste management activities in a MILP model are constrained by a set of system restriction, swine producer's resources and environmental regulation. Some of these are necessary for each time period and others affect the entire year.

1) System Restriction

As mentioned in previous chapter, the equation of system restriction insures that the model selects only one storage-application system in the optimal solution.

[Summation of Feasible Storage and Application Systems] = 1

$$\sum_i \sum_j SYSTEM_{ij} = 1 \qquad i \in I,\ j \in J \tag{5-13}$$

where $SYSTEM_{ij}$ = combination of all feasible storage structures i and application methods j with the integer 0-1

i = types of storage system (i = 1, ..., I)

j = types of application methods (j = 1, ..., J)

2) Constraints for Resources in Labor

Since labor availability may vary with time periods and type of waste handling systems, labor usage must be periodically constrained as follows:

[Total Labor Use in Effective System Operation in Time Period t]
≤ [Available Labor in Time Period t]

$$\sum_i \sum_j (REQLABH(ANIMALNO)_{ijt} \cdot SYSTEM_{ij}) \le AVALABOR_t \qquad \forall\ t \tag{5-14}$$

where $REQLABH(ANIMALNO)_{ijt}$ = labor hours required for operating storage system i and application system j in time period t as a function of animal numbers

$AVALABOR_t$ = available amount of labor in time period t

3) Accounting for Nutrient Availability

The nutrient availability from swine waste generated is given by:

[Effective Rate of Nutrient Release in System i and j] · [Manure Nutrient Generation] · [Time Constraint in System i and j] = [Available Manure Nutrient]

$$\sum_i \sum_j \sum_t SYSTEM_{ij} \cdot EFNRATE_{ni} \cdot EFNUTR_{nj} \cdot MNUTGR(ANIMALNO)_{nt} \cdot TIMECONST_{ijt} = AVMNUTR(ANIMALNO)_n \tag{5-15}$$

where $EFNRATE_{ni}$ = retention rate of nutrient n in storage system i
$EFNRATE_{nj}$ = retention rate of nutrient n in application system j
$MNUTGR(ANIMALNO)_{nt}$ = monthly amount of nutrient n generated in time period t as a function of animal numbers
$TIMECONST_{ijt}$ = time constraint for feasible application in storage structctures i and application system j in time period t
$AVMNUTR(ANIMALNO)_n$ = amount of available net nutrient n as a function of animal numbers

4) Constraint for Nutrient Requirements

Total nutrient requirement for each time period is determined by

[Acreage] · [Nutrient Requirement for Crop Production]
≤ [Total Nutrient Requirement]

$$\sum_c \sum_y \sum_t ACRENO_{cy} \cdot CROPUSE_{cnyt} \le TNUTREQ_n \tag{5-16}$$

where $ACRENO_{cy}$ = acreage of cropland with crop I and expected yield y
$TNUTREQ_n$ = total requirement of nutrient n

Then, the amount of commercial fertilizer required for crop production is determined by:

[Total Nutrient Requirement] - [Total Nutrient Supply]
≤ [Amount of Commercial Fertilizer Required]

$$TNUTREQ_n - AVNUTR(ANIMALNO)_n \leq AMFERT(ANIMALNO)_n \quad (5\text{-}17)$$

where $TNUTREQ_n$ = requirement of nutrient n
$AVNUTR(ANIMALNO)_n$ = total requirement of nutrient n as a function of animal numbers
$AMFERT(ANIMALNO)_n$ = amount of fertilizer n required as a function of animal numbers

Similarly, the constraint for nutrient requirement allows for determining the excess nutrients.

[Total Nutrient Supply] - [Total Nutrient Requirement Considering Over application Rate] ≤ [Excess Nutrients in Waste Utilization]

$$AVNUTR(ANIMALNO)_n - TNUTREQ_n \cdot (1 + MAXAPR_n) \leq EXNUTR(ANIMALNO)_n \quad (5\text{-}18)$$

where $TNUTREQ_n$ = requirement of nutrient n
$AVNUTR(ANIMALNO)_n$ = available nutrient n from swine manure as a function of animal numbers
$MAXAPR_n$ = maximum application rate of nutrient n, pound per acre
$EXNUTR(ANIMALNO)_n$ = excess nutrient n as a function of animal numbers

As mentioned above, there are excess nutrients (i.e., $EXNUTR_n \geq 0$), then the more land is needed to utilize the excess nutrients. In contrast, if there are insufficient nutrients then commercial fertilizer must be purchased.

5) Constraints on Used Additional Land

This equation determines the quantity of additional land necessary for utilization of excess nutrients.

[Excess Nutrients] -[Additional Land]·[Nutrient Requirement for Crop Production] ≤ 0

$$EXNUTR(ANIMALNO)_n - \sum_c \sum_y \sum_t ADDLAND_{cy} \cdot CROPUSE_{cnyt} \leq 0 \qquad (5\text{-}19)$$

where $EXNUTR(ANIMALNO)_n$ = excess nutrient n as a function of animal numbers
$ADDLAND_{cy}$ = additional land for crop c with yield y to be used for all excess nutrients
$CROPUSE_{cnyt}$ = requirement of nutrient n for crop c with expected yield y in time period t

6) Balance Equations for Storage Systems

Environmental concerns may limit the application of waste to land during certain periods of the year. Thus, facilities for the storage of waste must be constructed to meet the environmental constraints. For each time period, the inventory balance equation requires that beginning inventory of swine waste plus production of waste within the period is equal to the amount of waste spread on fields plus the ending waste inventory. So, the balance equation for manure storage is given by:

[Beginning Inventory of Waste Storage] + [Waste Volume Generated]
-[Amount of Waste Spread on Land] ≤ [Size of Waste Storage Required]

$$BEGINV_{it} + WASTVOL(ANIMALNO)_t - MHAULAM(ANIMALNO)_{it} \leq STORSIZE(ANIMALNO)_i \qquad (5\text{-}20)$$

where $BEGINV_{it}$ = beginning inventory of waste storage system i
$WASTVOL(ANIMALNO)_t$ = waste volume generated at time period t as a function of animal number
$MHAULAM(ANIMALNO)_{it}$ = monthly hauling amount of storage system i in time period t as a function of animal numbers (calculated from equation in (5-9))

STORSIZE(ANIMALNO)$_i$ = size of storage capacity in system i as a function of animal numbers

7) Environmental Regulations on Waste Handling Activity

This constraint insures that if the restriction concerning animal density per acre is enforced, then the model will add land in order to meet restriction, if not the producer already grow sufficient land.

[Acreage of Cropland] + [Additional Land] ≤ [Regulatory Requirement of Acreage]

$$\sum_c \sum_y [ACRENO_{cy} + ADDLAND(ANIMALNO)_{cy}] - \sum_i \sum_j \sum_s [ACREREQ(ANIMALNO)_{is} \cdot SYSTEM_{ij}] \geq 0 \qquad (5\text{-}21)$$

where $ACRENO_{cy}$ = acreage of cropland with crop c and expected yield y

$ADDLAND(ANIMALNO)_{cy}$ = additional land for crop c with expected yield y to be used for all excess nutrient as a function of animal numbers

$ACREREQ(ANIMALNO)_{is}$ = acreage requirement associated with storage system i to meet animal feeding unit s as a function of animal unit

5.3.4 Model Application

The analytical model described can be used in decision making process, when swine producers are to adapt a new waste management system. The model is based on the producers' managerial data (herd size and animal type, and land base and crops grown) suggests the optimal waste management system. In addition, the model can take into account assumptions concerning different environmental regulations (e.g., storage capacity or covering lagoon system), and different assumption of producers resources. All feasible scenarios can be evaluated by sensitivity analysis. The scenarios will be discussed in the next chapter.

Furthermore, regression equation of the annual total cost function and storage volume requirement drawn from the process of MILP solution will be used to formulate the linear programming model designed for determining the optimal strategy for waste management. Basically, the linear programming procedures used here to examine representative swine produces determine the optimal size of operation with the highest possible overall profitability, subject to resource constraints such as limited land, capacity of operation, manure for application to crops or pasture. In addition to a producer's overall profitability from crop and swine production, the result indicates that the shadow prices of limiting resources. The shadow prices of nutrient in the swine waste is positive, all swine waste has been applied and there are still more cost-saving opportunities to substitute swine waste nutrients for commercial fertilizer nutrients. If the shadow prices of a swine manure nutrient is negative, the swine producer has surplus waste under the scenario, and the last unit of manure produced has decreased net return by the amount of the shadow price.

5.4 Data Requirements and Collection

The data required and data sources are presented in Table 5-2. The technical data for climatic features were obtained from the *Atlas of Oklahoma Climate* (Johnson and Duchon, 1994). Information on soil characteristics, swine waste generation and its nutrient content, nutrient losses in waste management system, and space requirement for

Table 5-2 Data Requirements and Sources for the Integrated Decision Model

Items for data requirements	Sources
Climatic data (rainfall and evaporation)	· Johnson and Duchon (1994)
Soil characteristics	· USDA SCS (1961, 1979)
Waste generation and its nutrient content	· Midwest Plan Service (1993)
Nutrient losses in storage and application system	· Sutton (1996)
Space requirement for swine building	· Midwest Plan Service (1983)
Swine building construction cost	· Meridian Construction Co. (1997) and American Appraisal Associates (1995)
Designing waste storage structures	·USDA Codes and SCS (1992)
Construction costs of waste storage system	
- slurry tanks	· A.O. Smith Harvestore Products, Inc. (1997)
- outside storage pit	· Mid-America Ag System Inc.(1997) Agpro Inc. (1997)
- anaerobic lagoon	· USDA OK (1997)
Capital cost factors for waste handling equipment	· White and Forster (1979) and Dynan *et al.* (1981)
Equipment cost of waste application system	· American Appraisal Associates (1995), Hydro Engineering Inc. (1997), Cox (1993), and Reef Industries, Inc. (1997)
Costs of water supply and well drilling	· Kizer (1997) and Water Right Irrigation Inc. (1996)
Budgeting data for crop and hog production	
Prices of fertilizer nutrients	· CCES, Enterprise Budget (1995)
Unit costs of fuel, labor, tractor, and electricity	· OCES, Enterprise Budget (1995)
Rent of the cropland	· Oklahoma Agri. Statistics (1996)
Environmental regulations	
- CAFO requirements in Oklahoma	· OCAFOA (1997) and USDA NRCS (Oklahoma) (1995, 1996)
- animal density regulation on land basis	· Indiana Department of Environmental Management (1996)
- covering regulation of lagoons	· Babcock, Fleming, and Bundy (1997)

swine building were drawn from *Livestock Waste Facilities Handbook* (MWPS, 1993), *Swine Housing and Equipment Handbook* (MWPS, 1983), *Soil Survey* (USDA, 1961, 1972), and previous studies. In particular, the design standards on waste storage structures and application methods were based on a set of *USDA Codes* (USDA NRCS OK, 1995, 1996) and *Agricultural Waste Management Field Handbook* (USDA SCS, 1992). The information on costs coefficients used in the economic engineering approach were collected through solicited local contractors and distributors such as A.O. Smith Harvestore Products (De Kalb, IL), Mid-America Ag Systems Inc. (Salina, KS), Agpro Inc. (Paris, TX), Hydro Engineering Inc. (Salt Lake City, UT), and Water Right Irrigation, Inc. (Texoma, Oklahoma). The economic engineering model was used to estimate capital, operating, and maintenance costs for various alternative waste management systems in Oklahoma. The enterprise data on crop and swine production and unit costs of labor and energy were obtained from the *Enterprise Budget* (Oklahoma Coorporative Extension Station, 1995). All the data on monetary benefits and costs in each systems are in 1995 dollars. The environmental regulations on Oklahoma were based on the Oklahoma Concentrated Animal Feeding Operation Act (OCAFOA) of 1997, as discussed in the Chapter 3. The hypothetical environmental regulations on animal density and covering lagoon system were drawn from different state regulations such as Indiana and Iowa states, respectively. In addition, in order to generate data related to crop nutrient requirements for the expected yield given a specific soil, the EPIC (Erosion Productivity Impact Calculator) computer simulation model were incorporated into waste handling activities in the overall programming model, as stated above. It should be noted that the data collected are not real survey but generated for achieving the goal of this study. Some estimates were refined through consultation with extension personnel and through information obtained from the Texas county swine operations.

CHAPTER VI

ANALYTICAL RESULTS AND INTERPRETATIONS

This chapter presents the results of the integrated decision (ID) model. Sensitivity analysis is also presented. The volume requirement of the storage structures and the handling costs for each size and type of waste management systems are presented. The estimates of the annual capital and operating costs are presented for selected sizes of each system at each of the two study sites. Results of the mixed integer programming solutions to find the most profitable system for each size of finishing operation are presented for both study sites. The mixed integer programming model was used to determine the most profitable selection of waste storage structures and application system. The model also identifies the choice of on-farm or off-farm disposal of waste for selected sizes of finishing operations. The baseline mixed integer programming results assume the current environmental regulations in Oklahoma. The sensitivity of the results to changes in environmental regulations was determined by solving the models under the assumption that only nitrogen applied as waste was restricted to be less than crop uptake levels, and that an outside waste storage must be covered. The specific sections of this chapter include:

6.1 Model validation
6.2 Capacity Requirements of Waste Storage Structures
6.3 Capital Budgeting Analysis of Alternative Waste Management Systems
6.4 Results of Applying the Benchmark Model to Optimize Alternative Sizes and Types of Waste Handling Systems
6.5 Optimal Size of Swine Production-Waste Management System when Off-farm Waste Disposal is not Available
6.6 Impacts of Additional Environmental Regulation on the Swine CAFOs
6.7 Impact of the EQIP Program on Smaller Swine Operations

6.1 Model Validation

Model validation is an important concern of empirical economic analysis since the process becomes one of determining the model's usefulness for intended applications and/or the range of applications for which the model is valid. The validation process is divided into two types: validation by construct and validation by results (McCarl and Spreen, 1996). Validation by construct asserts the model was built properly using real world observations and therefore it is judged as valid. Validation by results refers to exercises where the model outputs are systematically compared against the real world observations.

Validation by construct is the most common way of validating mathematical programming models. The availability of nutrients generated from swine waste is the basic parameter for specifying the integrated decision model in this study. The validation by construct could be checked with previous research on the calculation of nutrient availability from swine waste. As shown in Table 6-1, available nutrients generated in the waste from a 1,000 head swine finishing operation were estimated by subtracting nutrient losses in storage and application systems. The differences of nitrogen availability between the ID model and MWPS calculation range from 101 pounds in the TANK-HAUL system to 227 pounds in the LAGOON-HAUL system. The available amount of manure nutrients calculated in this study are within 0.5 percent of estimates from the Midwest Plan Service (MWPS, 1993).

Validation by results consists of a comparison between the model solution and corresponding real world outcomes. Unfortunately, there are no recent or previous studies on the economic analysis of swine waste handling systems in Oklahoma. In this case, the model must be validated against a series or collection of industry level parameters (such as given by the Midwest Plan Service) and expert opinion. Difficulties arise when the same basic system considered by two or more sources contains different sub-components.

Table 6-1 Amounts of Swine Manure Nutrients Availability
- Case of 1,000 Head Finishing Pig Operation (ID model[a] vs. MWPS[b])

Waste Handling System	ID Model Nutrient Generation		MWPS Calculation Nutrient Generation		Difference	
	N	P_2O_5	N	P_2O_5	N	P_2O_5
	pounds					
TANK-HAUL	19,555	16,200	19,656	16,200	-101	0
PIT-HAUL	12,222	16,200	12,348	16,200	-126	0
PIT-PUMP	9,450	14,400	9,576	14,400	-126	0
LAGOON-HAUL	7,333	7,200	7,560	7,200	-227	0
LAGOON-PUMP	5,670	7,200	9,796	7,200	-126	0

[a] The ID modes represent the integrated decision model developed in this study.
[b] The MWPS Calculation refers to the methods of calculating the effective rate of manure nutrient application by the Midwest Plan Service (1993).

6.2 Capacity Requirements of Waste Storage Structures

As previously described, a pit recharge system is periodically drained by gravity to outside storage structures, and then recharged with a new liquid. The mechanism of recharging is that the addition of water to the pit on a regular basis keeps most manure solids in suspension in order to make removing the manure in the pit easier (Zhang and Lorimor, 1995). The recharging frequency depends upon the size of reception pit and air quality inside the building. The volume of water used for cleanup to hold the waste under the floor for moving solids to storage is an important factor in designing the waste storage structure. The additional water volume depends on the frequency with which the under pit water is changed and the desired level of total solid content. In this research, the dilution water volume used was 2.70 cu.ft./day per pig space. This figure assumed the underfloor reception pit is emptied every three days and then it is refilled to 1 foot of depth. Since it requires 8 square feet of floor space are required per finishing pig, this means that 8 cubic feet of water are required every 3 days for each pig. In addition, 0.03 cubic feet per pig space of cleaning water is required per day per animal.

Three storage systems representing basic differences in storage designs were analyzed based on the current environmental regulations in Oklahoma. The storage systems include a steel frame above ground slurry tank, an outside earthen pit, and an anaerobic single stage lagoon. Swine waste handling systems should include sufficient storage for the particular climate and cropping system to assure timely land application of the waste. Although the rules for the length of storage state 30 or 45 days of minimum storage, the baseline model was assumed to be 120 days of storage to allow sufficient time for crop application in the all systems.[35] Under the current environmental regulation in the OCAFOA (Oklahoma Statutes 1997, Section 9-204 and Section 9-205), the volume of

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[35] According to the Conservation Practice Standard by the NRCS (USDA NRCS OK, Code 313, 1996), the minimum storage period shall be 30 days for areas west of I-35 and 45 days for areas east of I-35.

storage structures must meet the design standards provided by the NRCS. The volume requirements were calculated based on the dilution water volume and safety factors. In particular, the minimum treatment volume of a lagoon system was calculated assuming that the maximum volatile solid loading rate was 5.3 lb/1,000 cu.ft/day in Texas county and 5.7 lb/1,000 cu.ft./day in Seminole county as suggested by the NRCS (USDA SCS, 1992). The sludge volume requirement assumes a 10 year accumulation period and that sludge accumulates at 0.0485 cu.ft/lb total solids in both study areas. The minimum requirement volume of storage structures is presented in Table 6-2. The volume requirement of the storage structures for each size of operation is shown in Figure 6-1 (Texas county) and Figure 6-2 (Seminole county). The volume requirement for the tank and pit systems in both study areas is larger than the volume for the lagoon because of the frequency with which the underfloor pits are refilled. The average volume requirement per pig space is 320 cu.ft. a for slurry tank system, 460 cu.ft. for a pit system, and 380 cu.ft. for a lagoon system in Texas county. In Seminole county, the average volume required per pig space is 320 cu.ft. for a tank system, 515 cu.ft. for a pit system, and 410 cu.ft. for a lagoon system. The differences in capacity for the earthen pit and lagoon systems between the two study areas were related to rainfall and evaporation. The capacity required for waste storage is greater in Seminole county than in Texas county because the former has higher net precipitation. Estimates for construction costs were based on the storage volume requirements for each system. The regression equations shown in Table 6-3 related the change in storage volume to change in the size of operation.

Table 6-2 Volume Requirement of Waste Storage Structures

Size of operation	Slurry Tank		Earthen Pit		Anaerobic Lagoon	
	Texas	Seminole	Texas	Seminole	Texas	Seminole
---head---	cubic feet					
500	171,000	171,000	241,561	284,240	193,321	217,668
1,000	342,000	342,000	465,551	537,590	380,091	418,316
2,000	684,000	684,000	913,532	1,044,291	756,209	819,612
3,000	1,026,000	1,026,000	1,361,512	1,550,992	1,146,468	1,220,908
4,000	1,368,000	1,368,000	1,809,492	2,057,693	1,506,727	1,622,204
5,000	1,710,000	1,710,000	2,257,244	2,564,394	1,881,986	2,023,500
6,000	2,052,000	2,052,000	2,705,452	3,071,094	2,257,244	2,424,796
7,000	2,394,000	2,394,000	3,153,432	3,577,795	2,632,503	2,826,092
8,000	2,736,000	2,736,000	3,601,412	4,084,496	3,007,762	3,227,389
9,000	3,078,000	3,078,000	4,049,392	4,591,196	3,383,020	3,628,685
10,000	3,420,000	3,420,000	4,497,372	5,097,897	3,758,280	4,029,980

Figure 6-1 Volume Requirement of Storage Structures under the Current Environmental Regulations in Oklahoma
- Case of Texas County -

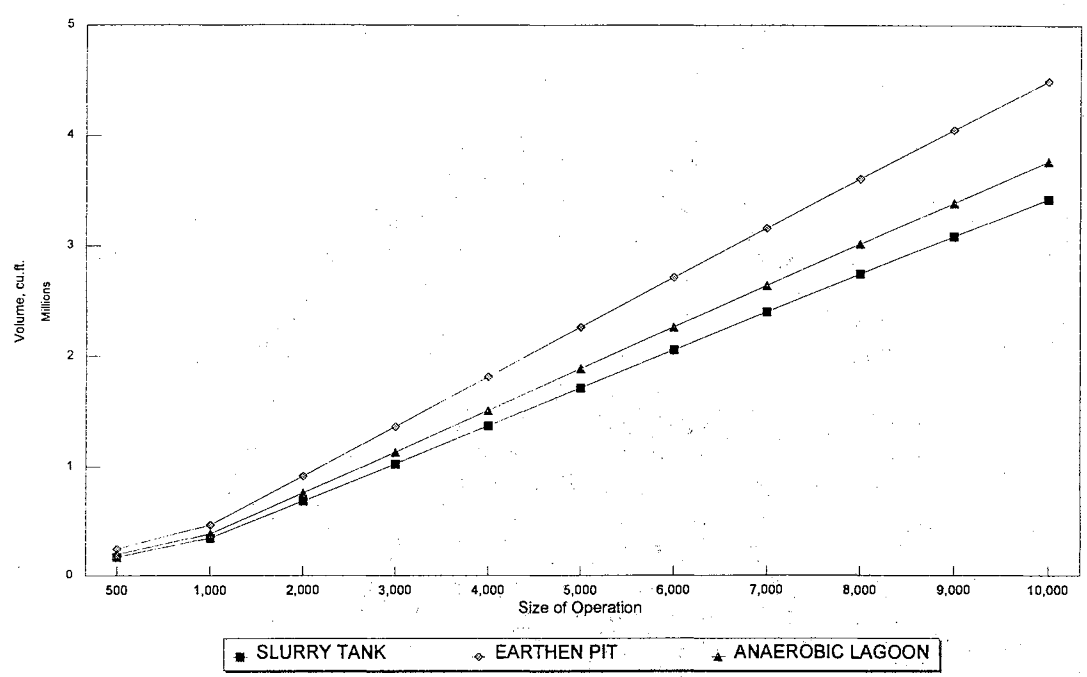


Figure 6-2 Volume Requirement of Storage Structures under the Current Environmental Regulations in Oklahoma
- Case of Seminole County -

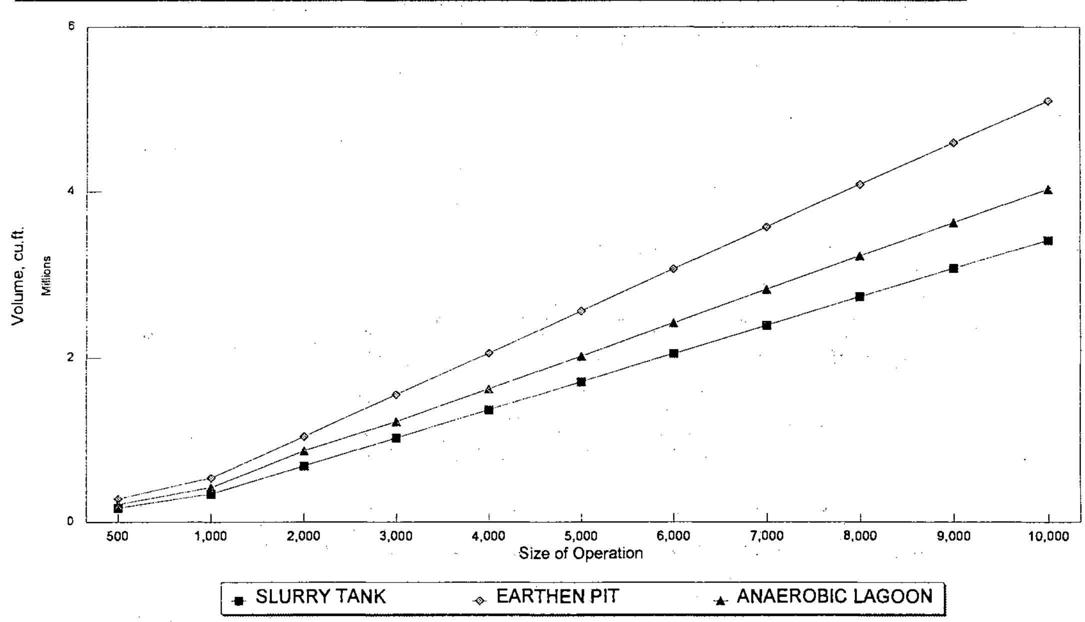


Table 6-3 Equation for Estimating Storage Volume Requirement under the OCAFOA

System	Regression Equation
	------------------ cu.ft. ------------------
Texas County	
Slurry Tank	TANKSIZE(PIGNO) = 342 * PIGNO
Earthen Pit	PITSIZE(PIGNO) = 17571.41 + 447.98 * PIGNO
Anaerobic Lagoon	LAGSIZE(PIGNO) = 5691.79 + 375.26 * PIGNO
Seminole County	
Slurry Tank	TANKSIZE(PIGNO) = 342 * PIGNO
Earthen Pit	PITSIZE(PIGNO) = 30889.65 + 506.7 * PIGNO
Anaerobic Lagoon	LAGSIZE(PIGNO) = 28866.64 + 399.85 * PIGNO

6.3 Capital Budgeting Analysis of Alternative Swine Waste Management Systems

Capital budgeting or economic engineering was used to estimate the annualized capital and operating costs for alternative sizes and types of waste management systems. It is assumed that the current environmental regulations in the Oklahoma Concentrated Animal Feeding Operation Act of 1997 were in effect. The related factors in these rules include nutrient restrictions in nitrogen and phosphorus uptake of the crop coverage, safety factors (e.g., precipitation, 25 year-24 hour storm event and freeboard) for a storage volume requirement, and 120 day storage period. The phosphorus restriction will be released in the sensitivity analysis.

The swine waste management systems were compared to see which was the most profitable or least costly for herd sizes from 500 to 10,000 head. The overall benefits of swine production and waste management systems were drawn from net revenues from crop (or forage) and swine production. The cost of buying and spreading commercial fertilizer was subtracted from the net revenue from crop production. The cost of commercial fertilizer was considered a separate factor and could be replaced by swine waste. The total annual cost is the sum of the annual capital investment cost (i.e., annual mortgage payments of interest and principal for buildings and equipment) plus the cost of operating the storage and application system. Only the costs for equipment and facilities used predominantly for swine waste management were fully charged to the waste management system. These items would most likely need to be purchased in order to install a particular waste system. Tractors used for hauling/spreading and center pivot were assumed to be resident on the swine enterprise prior to installation of a particular swine waste management system. One third of the price of the purchase price of a tractor (125 HP) was charged to the swine enterprise.

The TANK-HAUL system was the highest cost system among all the systems in both study areas while the lowest cost system appeared to be the LAGOON-PUMP system with center pivot irrigation in Texas county (Figure 6-3) and to be the LAGOON-PUMP system with a traveling gun sprinkler system in Seminole county (Figure 6-6). The reason for the difference is that the construction cost of the steel tank was very high but the construction cost for the lagoon was relatively low. The construction cost of a tank system for a 1,000 head finishing operation in Texas county was estimated at $321,480 which was 6.9 times higher than a pit system, and 8.4 times in a lagoon system, as shown

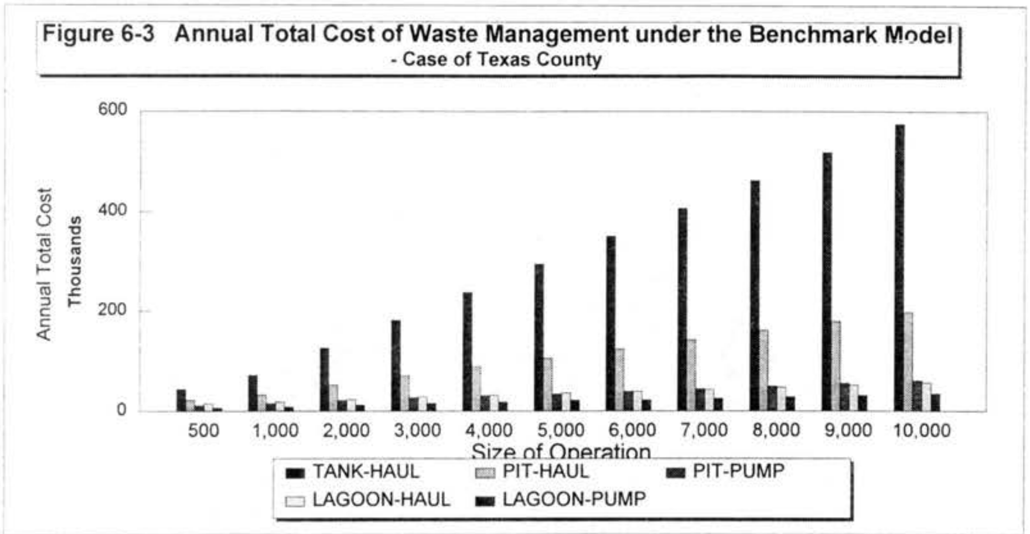


Figure 6-3 Annual Total Cost of Waste Management under the Benchmark Model
- Case of Texas County
Annual Total Cost
Thousands
600
400
200
0
500
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
Size of Operation
TANK-HAUL
PIT-HAUL
PIT-PUMP
LAGOON-HAUL
LAGOON-PUMP

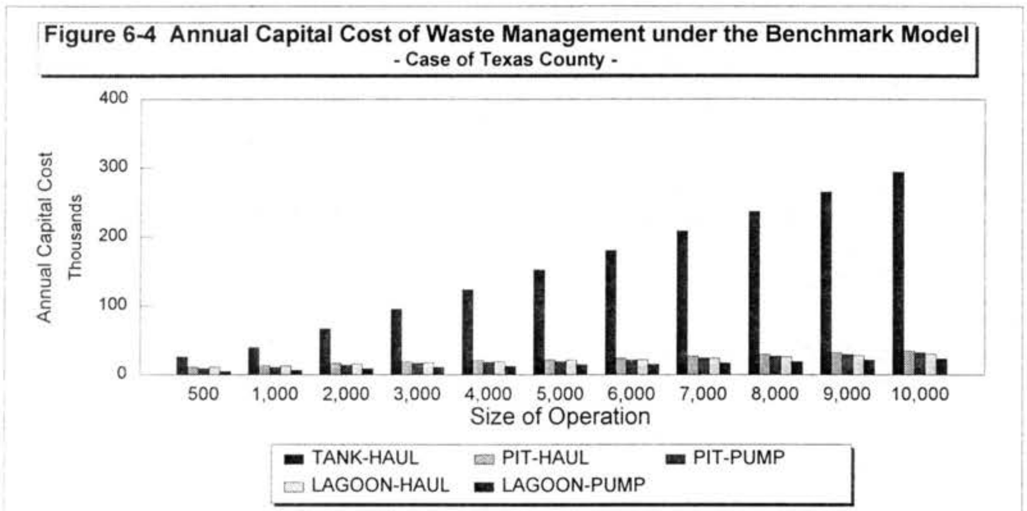


Figure 6-4 Annual Capital Cost of Waste Management under the Benchmark Model
- Case of Texas County -
Annual Capital Cost
Thousands
400
300
200
100
0
500
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
Size of Operation
TANK-HAUL
PIT-HAUL
PIT-PUMP
LAGOON-HAUL
LAGOON-PUMP

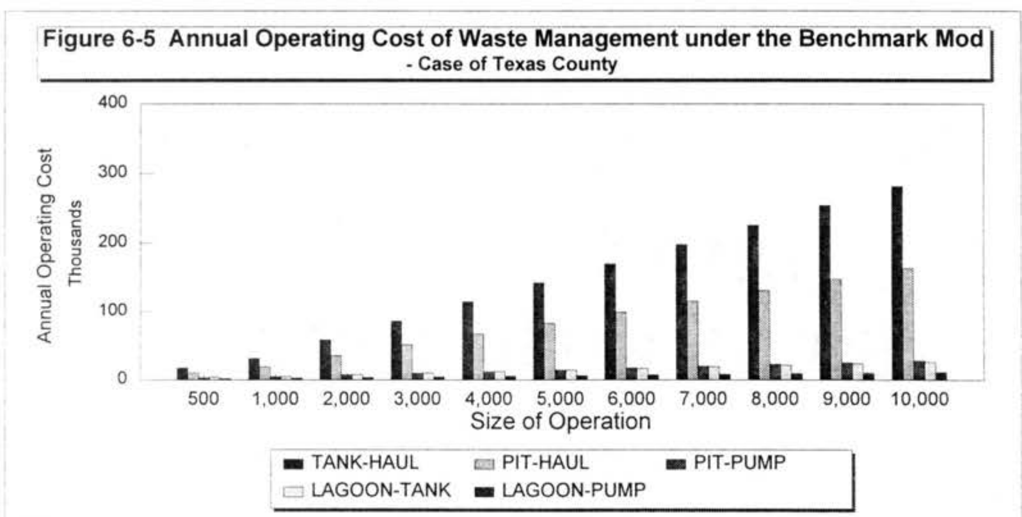


Figure 6-5 Annual Operating Cost of Waste Management under the Benchmark Mod
- Case of Texas County
Annual Operating Cost
Thousands
400
300
200
100
0
500
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
Size of Operation
TANK-HAUL
PIT-HAUL
PIT-PUMP
LAGOON-TANK
LAGOON-PUMP

Figure 6-6 Annual Total Cost of Waste Management under the Benchmark Model - Case of Seminole County

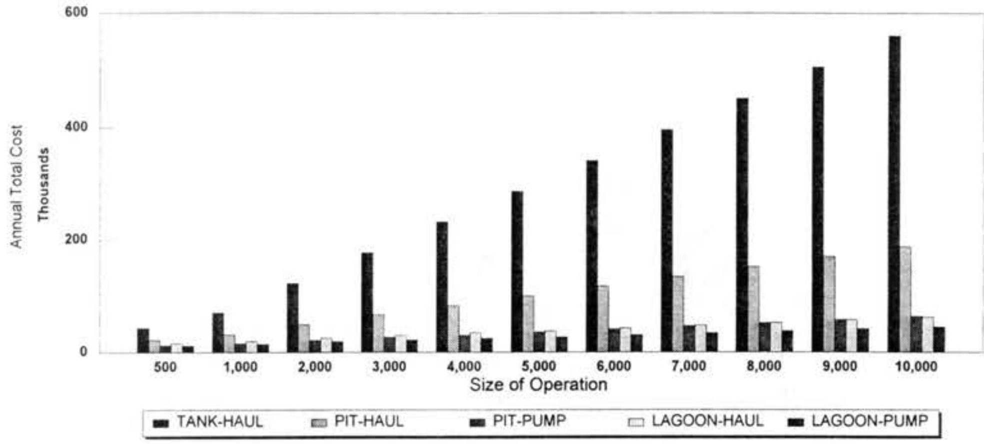


Figure 6-7 Annual Capital Cost of Waste Management under the Benchmark Model
Case of Seminole County

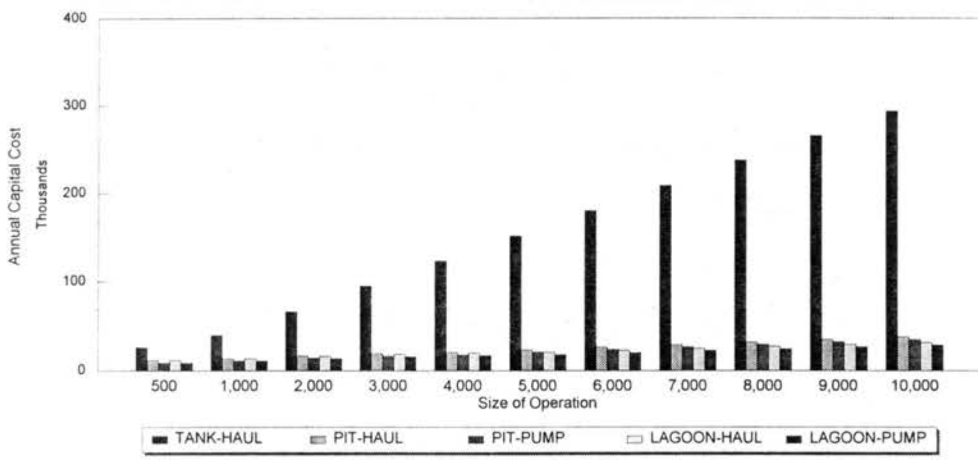
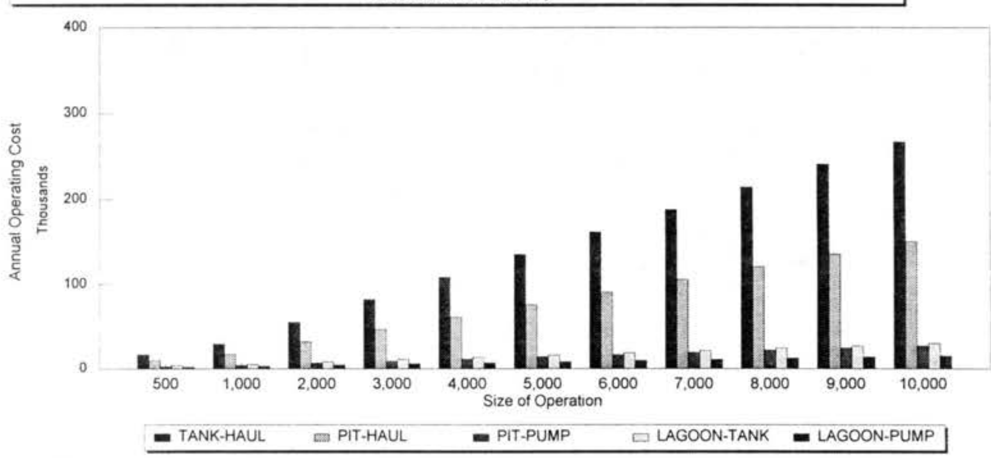


Figure 6-8 Annual Operating Cost of Waste Management under the Benchmark Model - Case of Seminole County



in Table 6-4. A tabular comparison of the total annual costs of various systems selected for operations consisting of 1,000 and 5,000 head are shown in Table 6-5. In Texas county, annual capital investment costs for various swine waste management systems for an operation consisting of 1,000 head ranged from $6,280 for the LAGOON-PUMP system to $40,031 for the TANK-HAUL system. For a 5,000 head operation, the annual capital investment cost ranged from $14,895 for the LAGOON-PUMP system to $150,043 for the TANK-HAUL system. The total annual operating cost for a 1,000 head operation waste management system ranged from $2,410 for the LAGOON-PUMP system to $31,126 for the TANK-HAUL system. Similarly, the annual operating cost for a 5,000 head operation ranged from $6,401 for the LAGOON-PUMP system to $142,161 for the TANK-HAUL system. Annual total cost for the 1,000 head operation ranged from $8,690 for the LAGOON-PUMP system to $71,157 for the TANK-HAUL system. And for a 5,000 head operation, the total annual cost ranged from $21,296 for the PIT-PUMP system to $294,204 for the TANK-HAUL system.

In Seminole county, annual capital investment cost of a swine waste management system for a 1,000 head operation ranged from $10,823 for the LAGOON-PUMP system to $40,031 for the TANK-HAUL system, as shown in Table 6-5. For an operation consisting of a 5,000 head, annual capital investment cost ranged from $18,144 for the LAGOON-PUMP system to $152,043 for the TANK-HAUL system. The annual operating cost for the waste management system for a 1,000 head operation ranged from $3,018 for the LAGOON-PUMP system to $29,646 for the TANK-HAUL system. The annual operating cost for a 5,000 head operation ranged from $8,283 for the

Table 6-4 Comparison of Waste Management Costs by System for a 1,000 Head Finishing Operation in Texas County

	Unit	TANK-HAUL	PIT-HAUL	PIT-PUMP	LAG-HAUL	LAG-PUMP
Storage Structures						
Storage size	cu.ft.	342,000	465,552	465,552	380,951	380,951
Storage construction cost	dollar	321,480	46,555	46,555	38,095	38,095
Fencing cost	dollar		1,752	1,752		
Equipment cost						
Side mount pump	dollar	10,000				
Prop agitator pump (100 HP)	dollar	7,150	7,150	7,150		
Chopper pump (100 HP)	dollar				13,000	13,000
Initial Investment cost	dollar	338,630	55,457	55,457	51,095	51,095
Annual cost for storage	dollar	32,748	6,126	6,126	5,909	5,909
Appication system						
Honey wagon (3,000 galon)	dollar	19,000	19,000		19,000	
Tractor (1/3 price of 125 HP)	dollar	17,666	17,666		17,666	
Injector	dollar	2,700	2,700		2,700	
Travel gun	dollar			20,100		
PVC pipe (1/4 mile 6"PVC)	dollar			3,432		3,432
Sludge hose (660')	dollar			1,168		
Initital investment cost	dollar	39,366	39,366	24,700	39,366	3,432
Annual cost for application	dollar	7,283	7,283	4,570	7,283	371
Annual capital cost		40,031	13,409	10,696	13,192	6,280
Operating cost						
Maintenance cost	dollar	15,513	3,290	2,162	3,120	1,852
Hauling cost	dollar	14,796	14,797		1,419	
Hauling hour (hour)	hour	496	496		48	
Labor cost	dollar	2,976	2,976		288	
Irrigation cost	dollar			1,297		35
Pumping hour	hour			248		10
Energy cost	dollar			425		15
Labor cost	dollar			68		1
Water supply cost	dollar	777	777	777	486	486
License fee	dollar	38	38	38	38	38
Annual operating cost	dollar	31,124	18,902	4,274	5,063	2,411
Total Annual Cost	dollar	71,155	32,311	14,970	18,255	8,691

Table 6-5 Engineering Costs of Alternative Waste Management Systems

	Annualized Cost		
	Total Cost	Capital Cost	Operating Cost
	------------ dollar/system (dollar/head capacity) ---------------		
Texas County			
1,000 Head Size			
TANK-HAUL	71,157 (71.16)	40,031 (40.00)	31,126 (31.12)
PIT-HAUL	32,311 (32.31)	13,409 (13.40)	18,902 (18.90)
PIT-PUMP	14,971 (14.97)	10,696 (10.70)	4,275 (4.28)
LAGOON-HAUL	18,255 (18.26)	13,192 (13.19)	5,063 (5.06)
LAGOON-PUMP	8,690 (8.69)	6,280 (6.28)	2,410 (2.41)
5,000 Head Size			
TANK-HAUL	294,204 (58.84)	150,043 (30.00)	142,161 (28.43)
PIT-HAUL	105,109 (21.02)	22,009 (4.40)	83,100 (16.62)
PIT-PUMP	33,773 (6.75)	19,296 (3.85)	14,477 (2.89)
LAGOON-HAUL	36,316 (7.26)	21,807 (4.36)	14,509 (2.90)
LAGOON-PUMP	21,296 (4.25)	14,895 (3.00)	6,401 (1.28)
Seminole County			
1,000 Head Size			
TANK-HAUL	69,677 (69.68)	40,031 (40.00)	29,646 (29.65)
PIT-HAUL	31,049 (31.05)	13,588 (13.59)	17,461 (17.46)
PIT-PUMP	15,059 (15.06)	10,875 (10.88)	4,184 (4.18)
LAGOON-HAUL	19,104 (19.10)	13,536 (10.54)	5,568 (5.57)
LAGOON-PUMP	13,841 (13.84)	10,823 (10.82)	3,018 (3.02)
5,000 Head Size			
TANK-HAUL	286,806 (57.36)	152,043 (30.41)	134,763 (26.95)
PIT-HAUL	99,786 (19.95)	23,714 (4.74)	76,072 (15.21)
PIT-PUMP	35,200 (7.04)	21,001 (4.20)	14,199 (2.84)
LAGOON-HAUL	37,144 (7.43)	20,857 (4.17)	16,287 (3.26)
LAGOON-PUMP	26,427 (5.29)	18,144 (3.63)	8,283 (1.66)

Note: The figures in the parentheses represent the average cost per pig space associated with each cost category.

LAGOON-PUMP system to $134,763 for the TANK-HAUL system. Annual total cost of 1,000 head operation ranged from $13,841 for the LAGOON-PUMP system to $69,677 for the TANK-HAUL system. For the 5,000 head operation, the total annual cost ranged from $26,427 for the LAGOON-PUMP system to $286,806 for the TANK-HAUL system.

The annual total cost per pig space estimates shown in Figure 6-9 to Figure 6-11 (Texas county) and Figure 6-12 to Figure 6-14 (Seminole county) show the total annual cost per pig space for all the waste treatment systems declines sharply as herd size increases. This illustrates the economies of size in swine waste handling systems. In the case of the LAGOON-PUMP system, the annual total cost per pig space decreased 3.7 times in Texas county and 5.0 times in Seminole county, as the size increased from a 500 to a 10,000 head operation. For example, the annual capital cost per pig space for a LAGOON-PUMP system in Texas county was estimated at $12.61 per head for a 500 head operation and at $6.30 per head for a 2,000 head operation. The cost per head of all waste management systems declined sharply until the 2,000 head size was reached and declined more slowly until the 3,000 to 4,000 size was reached. The reason for this can be explained by fixed costs in pump systems and application equipment.

The relationship between total annual cost and herd size can be summarized by simple regression equations, in Table 6-6. The slope term represents the marginal or incremental cost per additional animal while the intercept term represents a fixed cost for the system. For example, the incremental waste management cost for one more pig in

Figure 6-9 Annual Total Cost Per Pig Space of Waste Management
- Under the Benchmark Model in Texas County

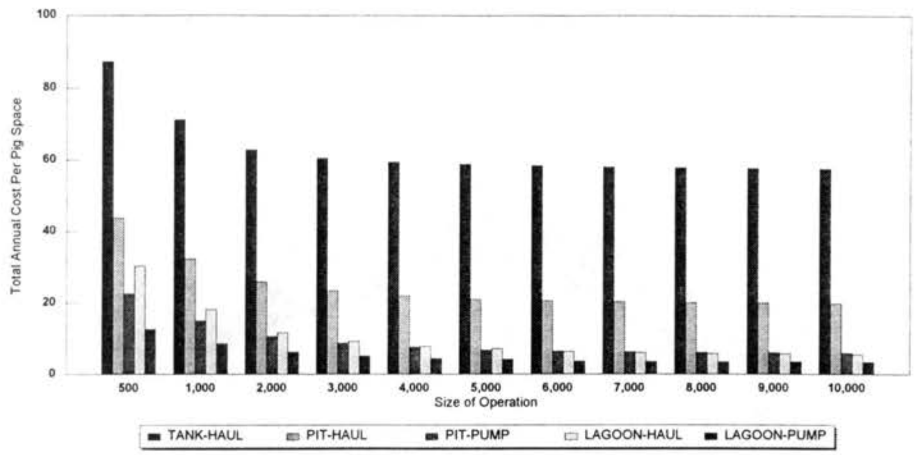


Figure 6-10 Annual Capital Cost per Pig Space of Waste Management
- Under the Benchmark in Texas County

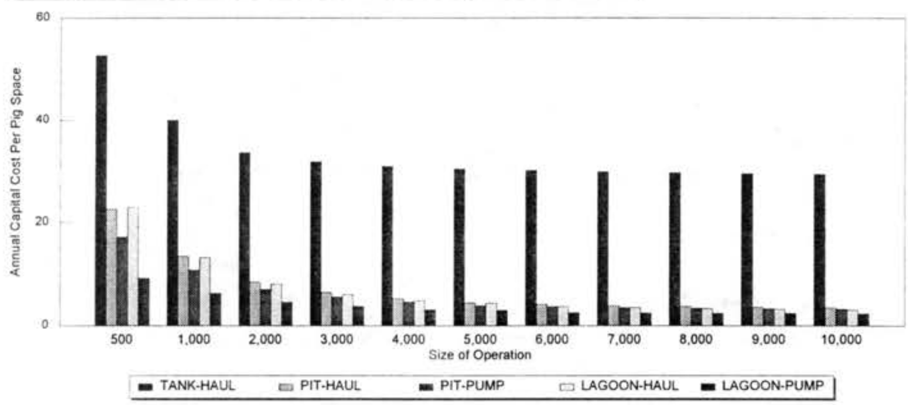


Figure 6-11 Annual Operating Cost Per Pig Space of Waste Management
- Under the Benchmark Model in Texas County

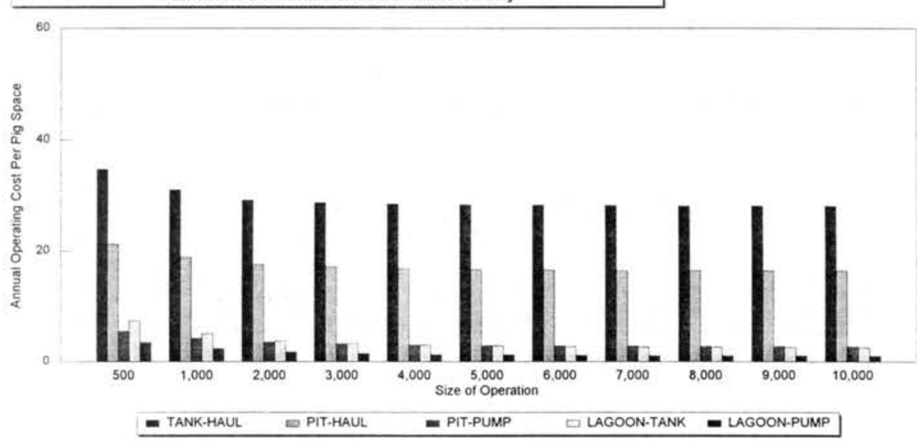


Figure 6-12 Annual Total Cost per Pig of Waste Management
- Under the Benchmark in Seminole County

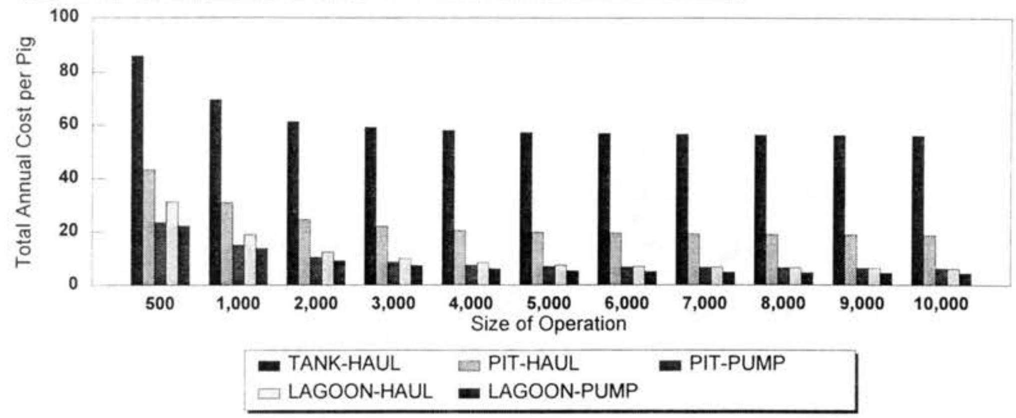


Figure 6-13 Annual Capital Cost per Pig of Waste Management
- Under the Benchmark Model in Seminole County

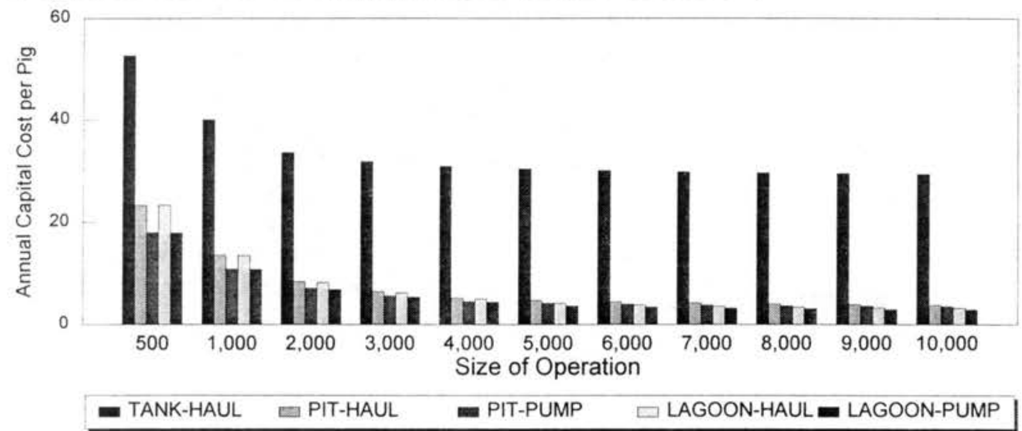
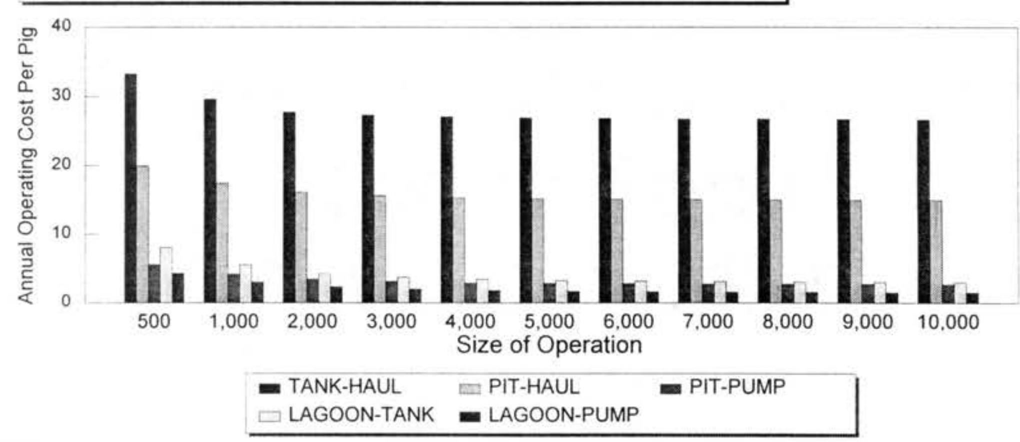


Figure 6-14 Annual Operating Cost per Pig of Waste Management
- Under the Benchmark in Seminole County



Texas county is \$2.81 with the LAGOON-PUMP system. The average total cost per pig space is \$2.81 + \$6,196/No. head. The equations of an annual total cost can be used for determining optimal size of an operation in the linear programming model.

Table 6-6 Annual Total Cost Functions of Alternative Waste Handling Systems

Alternative systems	Annual Total Cost Functions
	------------- dollar -------------
Texas County	
TANK-HAUL System	$ATC(PIGNO)_{TANK\text{-}HAUL} = 14414.25 + 56.04 * PIGNO$
PIT-HAUL System	$ATC(PIGNO)_{PIT\text{-}HAUL} = 14017.86 + 18.43 * PIGNO$
PIT-PUMP System	$ATC(PIGNO)_{PIT\text{-}PUMP} = 10176.76 + 4.93 * PIGNO$
LAGOON-HAUL System	$ATC(PIGNO)_{LAG\text{-}HAUL} = 14397.59 + 4.17 * PIGNO$
LAGOON-PUMP System	$ATC(PIGNO)_{LAG\text{-}PUMP} = 6196.45 + 2.81 * PIGNO$
Seminole County	
TANK-HAUL System	$ATC(PIGNO)_{TANK\text{-}HAUL} = 14414.41 + 54.56 * PIGNO$
PIT-HAUL System	$ATC(PIGNO)_{PIT\text{-}HAUL} = 13392.68 + 17.41 * PIGNO$
PIT-PUMP System	$ATC(PIGNO)_{PIT\text{-}PUMP} = 9551.70 + 5.26 * PIGNO$
LAGOON-HAUL System	$ATC(PIGNO)_{LAG\text{-}HAUL} = 14507.63 + 4.72 * PIGNO$
LAGOON-PUMP System	$ATC(PIGNO)_{LAG\text{-}PUMP} = 10608.50 + 3.35 * PIGNO$

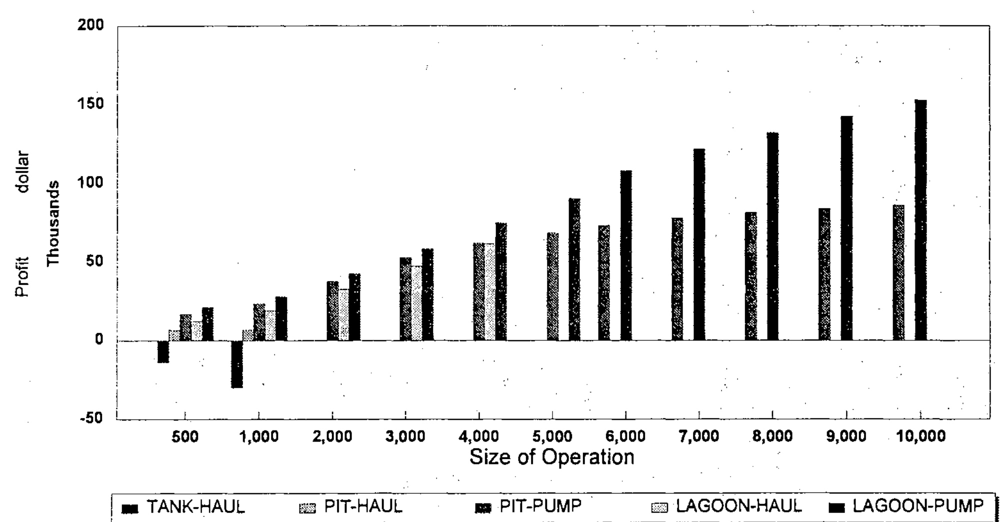
6.4 Results of Applying the Benchmark Model to Optimize Alternative Sizes and Types of Waste Handling Systems

This section will illustrate how the integrated decision model can help to select the optimal waste management systems for representative swine producers. After the GAMS-ZOOM had solved the MILP problems, the optimal system was chosen for swine waste management with different sizes of operation. The general regulations throughout the state limit applications of nitrogen in waste to not exceed plant uptake by more than thirty percent. In areas of the state where local water quality is threatened by phosphorus, waste applications of phosphorus are limited as written in the most current Natural Resources Conservation publication entitled Waste Utilization Standard (O.S., Section 9-(C)-(4)-(a)). The baseline results of the mixed integer programming assume the producer plans as if the nitrogen and phosphorus restrictions are in effect. Other essential regulations assume that waste storage structures have at least four months storage capacity along with volume adequate for holding the contents of the maximum recorded 24- hour rainfall observed in a 25-year period.

6.4.1 Selection of the Optimal Waste Management System

In Texas county, the benchmark model for the standard of reference assumes the producer has 256 acres of irrigated cropland under center pivot irrigation, has 160 hours labor available for waste handling activity, and has minimum storage capacity for four months of waste generation, and must limit nitrogen and phosphorus applications to crop uptake levels. The profitability of each system with each size of swine operation is presented graphically in Figure 6-15. The total profitability of a swine production and waste management system increased with herd size for all systems, except for the TANK-HAUL system. As shown in Table 6-7, the annual profitability with the LAGOON-PUMP and the PIT-PUMP systems ranged from $21,118 and $16,954 for a 500 head size to $152,384 and $85,823 for the 10,000 head operation, respectively. The TANK-HAUL and PIT-HAUL systems over 2,000 head operations and the LAGOON-HAUL system over 5,000 head operation were left out in evaluating the most profitable waste management system since those systems could not meet the labor constraint for 160 hours per month.[36] The most profitable system across all the sizes of operations was found to be the LAGOON-PUMP while the second best system was the PIT-PUMP system. This

Figure 6-15 Overall Profitability under the Benchmark Model
- Case of Texas County -



36 The analytical results showed that the monthly labors of hauling application for 2,000 head operation were 198 hours in the TANK-HAUL and PIT-HAUL systems in Texas county. In the case of the LAGOON-HAUL system, the labor hours required for hauling application were 157 hours for a 4,000 head operation and 196 hours for a 5,000 head operation.

Table 6-7 Profitability of Selected Waste Management Systems by Size of Operations in Texas County

Size of operation	Overall profitability[a)]	Annual cost Total	Annual cost Per pig space	Fertilizer cost	Additional land	Rank	Selected systems
-- head --	dollar				--acre----		
500	21,118	6,306	12.61	22,078	0	1	LAGOON-PUMP
	16,954	11,339	22.68	21,210	0	2	PIT-PUMP
1,000	28,069	8,690	8.69	20,974	0	1	LAGOON-PUMP
	23,525	14,971	14.97	19,237	0	2	PIT-PUMP
2,000	42,824	12,604	6.30	18,764	0	1	LAGOON-PUMP
	37,697	21,205	10.60	15,290	0	2	PIT-PUMP
3,000	58,459	15,639	5.21	16,555	0	1	LAGOON-PUMP
	52,911	26,398	8.80	11,344	0	2	PIT-PUMP
4,000	74,933	17,834	4.46	14,345	0	1	LAGOON-PUMP
	61,950	30,587	7.65	8,470	52	2	PIT-PUMP
5,000	91,141	21,296	4.26	12,136	0	1	LAGOON-PUMP
	68,599	33,773	6.75	6,108	129	2	PIT-PUMP
6,000	107,876	22,230	3.71	9,926	0	1	LAGOON-PUMP
	73,164	38,986	6.50	3,745	206	2	PIT-PUMP
7,000	121,624	25,272	3.61	7,998	14	1	LAGOON-PUMP
	77,765	44,199	6.31	1,383	283	2	PIT-PUMP
8,000	131,878	28,389	3.55	6,580	52	1	LAGOON-PUMP
	81,311	49,486	6.19	0	360	2	PIT-PUMP
9,000	142,207	31,431	3.49	5,163	91	1	LAGOON-PUMP
	83,538	54,699	6.08	0	437	2	PIT-PUMP
10,000	152,534	34,473	3.45	3,745	129	1	LAGOON-PUMP
	85,823	59,911	5.99	0	514	2	PIT-PUMP

[a)] The overall profitability includes total net returns from swine and irrigated corn. Annual net return from swine production can be determined by subtracting the net return from corn without irrigation ($18,089/256 acre, i.e, 70.66/acre) from the overall profitability for each size.

analytical result can be explained by the relationships among various waste handling costs, between the fertilizer value, offsite hauling cost for excess nutrient disposal, and the nutrient content of waste shown in the sequence of diagrams from Figure 6-16 to Figure 6-18. There exists a trade-off relationship between total annual cost of waste handling activity and fertilizer cost. The fertilizer cost declines with the size of operation because commercial fertilizer is replaced by manure application. The PIT-PUMP system retains more nutrients for cropland use than does the LAGOON-PUMP system. However, the PIT-PUMP system has a larger annual total cost for all sizes of operation than the LAGOON-PUMP system. In particular, excess phosphorus nutrient applications under the current OCAFOA are not allowed in the phosphorus buildup area. In such a case, disposal costs for excess phosphorus nutrients are needed.[37] When this point was reached, it was assumed the producer would hire a custom hauler for disposal. The costs of excess nutrient disposal with the PIT-PUMP system increase rapidly when operation size exceeds 4,000 head. Custom hauling cost of excess nutrients does not begin with the LAGOON-PUMP system until the operation reaches 8,000 head. Since a lagoon system retains fewer nutrients than the pit system, the lagoon system requires less additional land area for disposal as the size of operation increases. Thus, the LAGOON-PUMP system was more profitable than the PIT-PUMP system as shown in Figure 6.18.

In the Seminole county case, the producer was assumed to have 200 acres of irrigated Bermuda grass which could be used for waste disposal, 4 months of storage

[37] The excess nutrient disposal cost using the custom hauling method in Texas county was \$116.66/acre calculated from allowing 186 pounds of phosphorus used per acre for corn production and \$0.20/cu.ft. of custom hauling cost.

Figure 6-16 Major Costs of PIT-PUMP System under the Benchmark Model
Case of Texas County

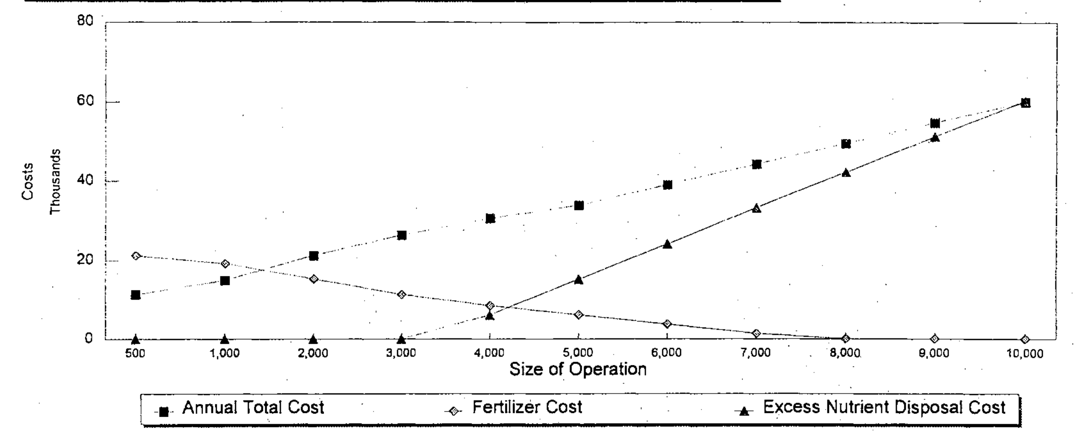


Figure 6-17 Major Costs of the LAGOON-PUMP System under the Benchmark Model
- Case of Texas County

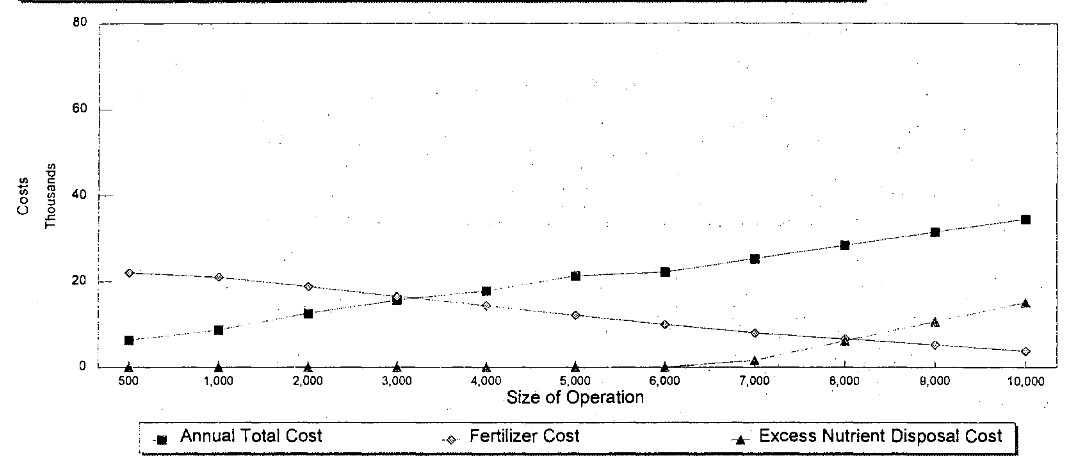
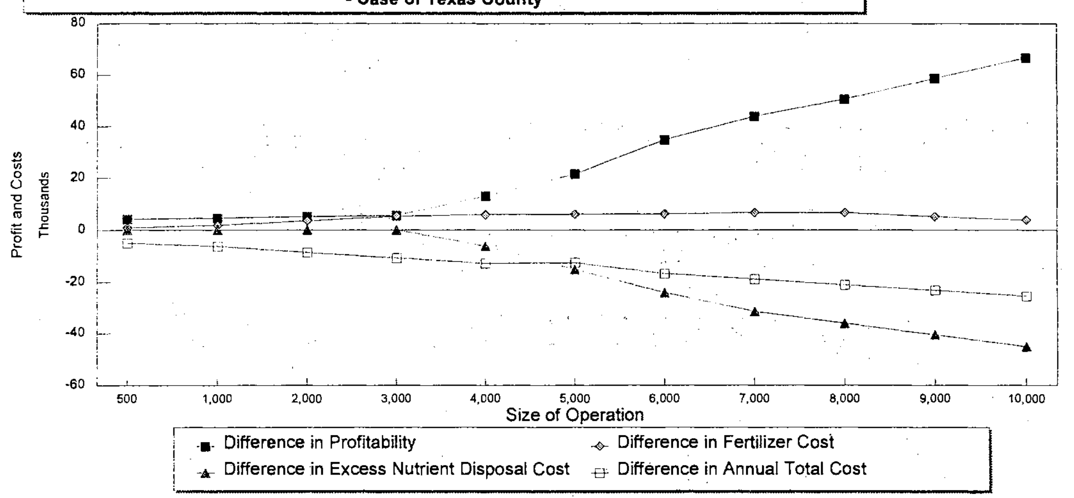
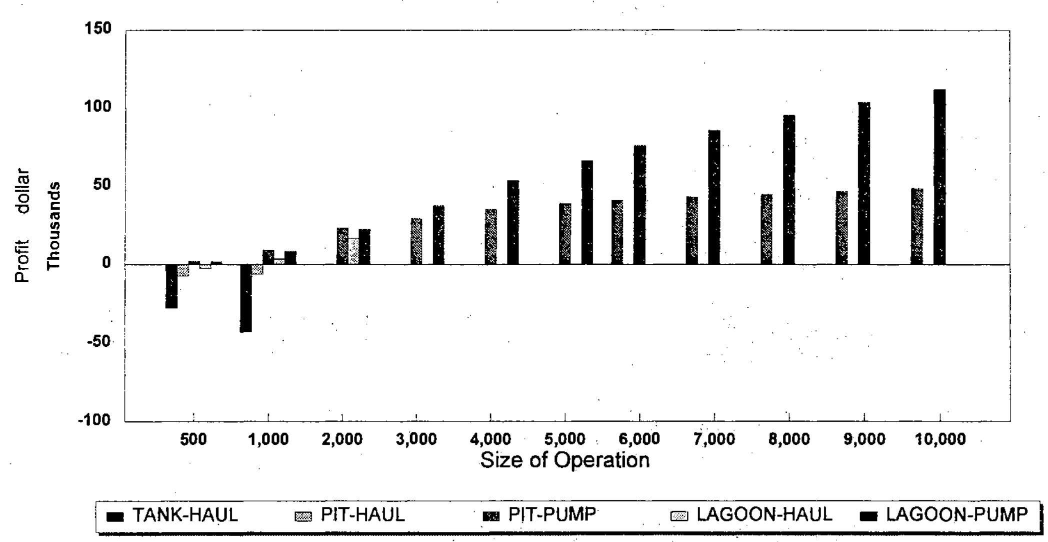


Figure 6-18 Profits and Costs between LAGOON-PUMP and the PIT-PUMP systems
- Case of Texas County



capacity for waste. Maximum application rates are limited to crop uptake of nitrogen and phosphorus.[38] The profitability of each system with each size of operation is presented in Figure 6-19. The overall profitability of the production and waste management system increased as herd size increased. As shown in Table 6-8, the overall profitability of the PIT-PUMP and the LAGOON-PUMP systems ranged from $2,003 and $1,782 for a 500 head operation to $23,270 and $22,539 for a 2,000 head operation, respectively. The TANK-HAUL and PIT-HAUL systems exceed 2,000 head and the LAGOON-HAUL system exceeds 4,000 head were not considered further since the hauling labor exceeds the allowable 160 hours per month. The PIT-PUMP system was the most profitable system for operations of less than 2,000 head. However, it was only $221 more profitable than the LAGOON-PUMP system for the 500 head operation. The LAGOON-PUMP

Figure 6-19 Overall Profitability under the Benchmark Model
- Case of Seminole County -



[38] According to the classification of conservation priority areas in Oklahoma, Seminole county was categorized in the phosphorus build-up area (Sanders, 1997).

Table 6-8 Profitability of Selected Waste Management Systems by Size of Operation in Seminole County

Size of operation	Overall profitability[a)]	Annual cost Total	Annual cost Average	Fertilizer cost	Additional land	Rank	Selected systems
-- head	-------- dollar	--------	--------	--------	--acre----		
500	2,003	11,765	23.53	12,688	0	1	PIT-PUMP
	1,782	11,117	22.23	13,557	0	2	LAGOON-PUMP
1,000	8,912	15,059	15.06	10,715	0	1	PIT-PUMP
	8,393	13,841	13.84	12,452	0	2	LAGOON-PUMP
2,000	23,270	21,107	10.55	6,769	0	1	PIT-PUMP
	22,539	18,364	9.18	10,243	0	2	LAGOON-PUMP
3,000	37,622	21,951	7.32	8,033	0	1	LAGOON-PUMP
	29,181	25,982	8.66	4,254	86	2	PIT-PUMP
4,000	53,604	24,638	6.16	5,824	0	1	LAGOON-PUMP
	35,201	29,722	7.43	1,892	182	2	PIT-PUMP
5,000	66,184	26,427	5.29	4,254	39	1	LAGOON-PUMP
	39,011	35,200	7.04	0	277	2	PIT-PUMP
6,000	75,924	30.032	5.01	2,837	86	1	LAGOON-PUMP
	40,931	40,677	6.78	0	372	2	PIT-PUMP
7,000	85,665	33,637	4.81	1,419	134	1	LAGOON-PUMP
	42,841	46,155	6.59	0	468	2	PIT-PUMP
8,000	95,329	37,318	4.66	2	182	1	LAGOON-PUMP
	44,686	51,707	2.98	0	563	2	PIT-PUMP
9,000	103,653	40,923	4.55	0	229	1	LAGOON-PUMP
	46,604	57,185	6.35	0	658	2	PIT-PUMP
10,000	111,975	44,529	4.45	0	277	1	LAGOON-PUMP
	48,524	62,662	6.27	0	754	2	PIT-PUMP

a) The overall profitability includes total net returns from swine and irrigated bermuda. The net returns from swine production can be calculated by subtracting the net return from pasture production without irrigation ($3,564/200 acre, i.e., $17.82/acre) from the overall profitability.

system was the most profitable for operations over 3,000 head. The reason for this result is the same as for the Texas county case. The capacity of the available land to accept waste nutrients is exhausted more quickly with the PIT-PUMP system than with the LAGOON-PUMP system as shown in Figures 6-20 to 6-22. The capacity of the land to utilize the nutrients with the PIT-PUMP system is exceeded when the herd size reaches 2,000 head. It was assumed the producer would hire a custom hauler for disposal when the maximum nutrient limitation phosphorus area reached.[39] The excess nutrient disposal costs with the PIT-PUMP system increase rapidly when the operation size exceeds 3,000 head. Costs for excess nutrient disposal do not begin with the LAGOON-PUMP system until the operation size exceeds 4,000 head. The differences of major costs between the PIT-PUMP system and LAGOON-PUMP system are graphically described by Figure 6-22.

From the analytical results mentioned above, a general recommendation of an optimal system as "best" for all swine operations in both study sites is not feasible. However, for all sizes of operations in Texas county the LAGOON-PUMP system was the most profitable. The profitability of the LAGOON-PUMP system with center pivot irrigation was in large part because the pivot was assumed to exist and the water and nutrients from the lagoon system replaces purchased fertilizer and water that would normally be pumped for irrigation. In particular, in the case of larger operations of 3,000 to 10,000 head, the lagoon was the best handling system because much of the nitrogen is

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[39] The excess nutrient disposal cost using custom hauling in Seminole county used $95.29/acre which was calculated from allowing 151 pounds of phosphorus to be utilized per acre for Bermuda production and $0.20/cu.ft. for custom hauling.

Figure 6-20 Major Costs in PIT-PUMP System under the Benchmark Model
- Case of Seminole County

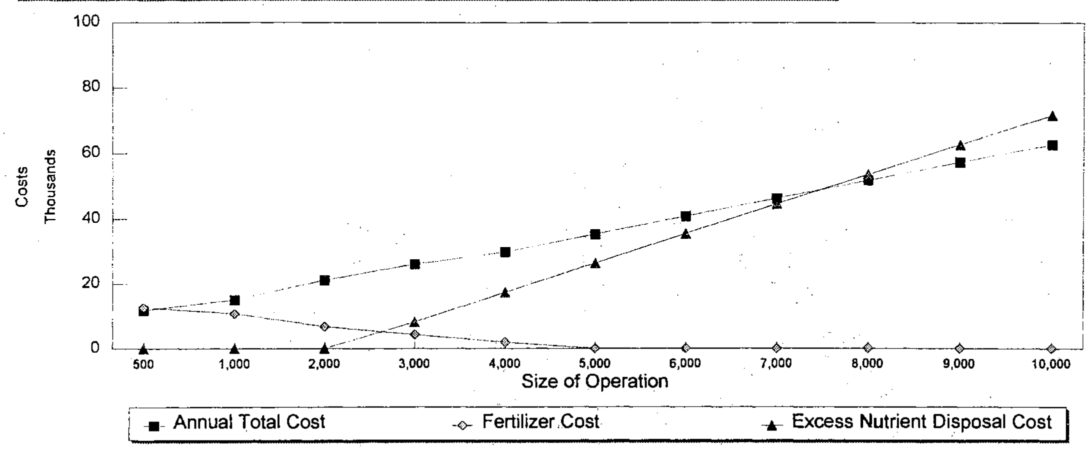


Figure 6-21 Major Costs in the LAGOON-PUMP System under the Benchmark Model
- Case of Seminole County

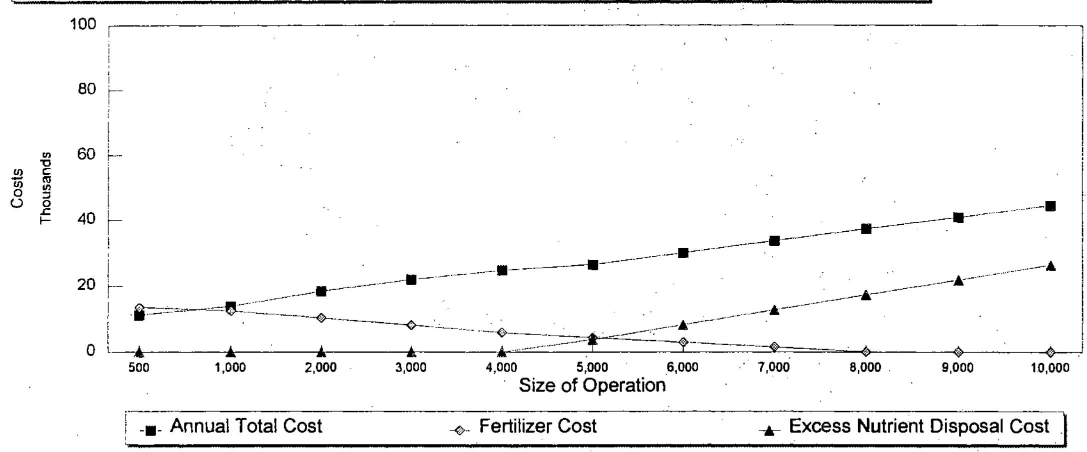
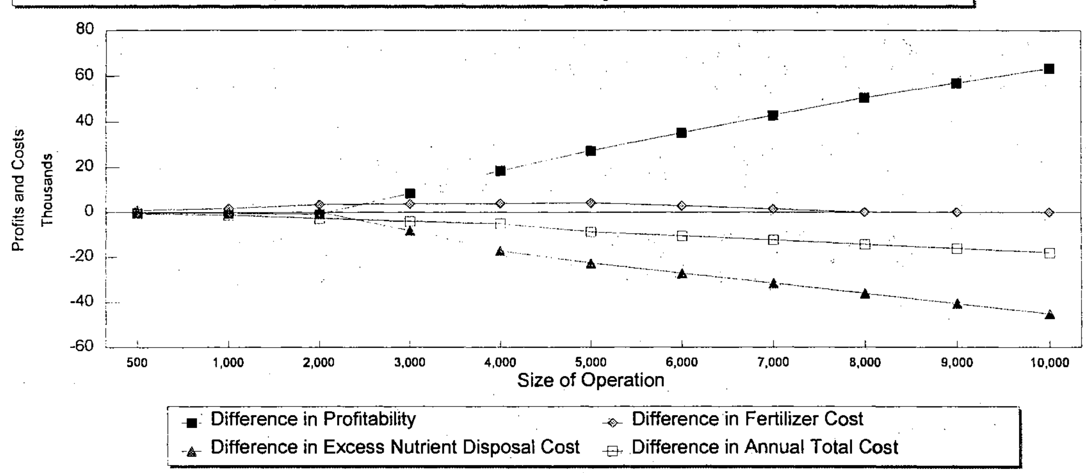


Figure 6-22 Profit and Costs Between the LAGOON-PUMP and the PIT-PUMP Systems
- Case of Seminole County



volatilized while much of the phosphorus remains with the sludge. Similarly, in the case of Seminole county, the LAGOON-PUMP system with a traveling gun irrigation was the most profitable waste handling system for operation with more than 3,000 head.

6.4.2 Loss of Profitability Due to the Wrong Decision

The results of the integrated decision (ID) model were used to calculate the opportunity cost of making the wrong decision in selecting a waste handling system shown in Table 6-9. For example, if the TANK-HAUL system or the PIT-HAUL system were selected for a 1,000 head operation rather than the LAGOON-PUMP system, a swine producer's profitability would be reduced by $58,005 or $21,191, respectively. So, there would be a profitability loss of $58.01 per pig space for the TANK-HAUL system and $21.19 per pig space for the PIT-HAUL system.

In Seminole county, the most profitable system for operations with less than 2,000 head was the PIT-PUMP system. If the LAGOON-PUMP system or the TANK-HAUL system were selected for a 500 head operation, a swine producer's profitability would be reduced by $221 or $29,843, respectively. The loss in profitability is $0.44 per pig space from choosing the LAGOON-PUMP system or $59.69 per pig space from choosing the TANK-HAUL system. The LAGOON-PUMP system for operations larger than 3,000 head was found to be the most profitable waste handling system. Selecting the PIT-PUMP system for a 3,000 head operation would reduce the profitability by $8,441, or $2.81 per pig space. As mentioned above, the TANK-HAUL, PIT-HAUL, and LAGOON-HAUL systems were omitted for operations of more than 4,000 head because they required more than 160 hours per month.

Table 6-9 Comparison of Loss of Profitability Due to Wrong System Selection

	Texas County			Seminole County		
	Rank	Total loss	Loss per pig	Rank	Total Loss	Loss per pi
		---- dollar ---	dollar/head-		---- dollar ---	dollar/head-
500 HEAD						
TANK-HAUL	5	-35,172	-70.34	5	-29,843	-59.69
PIT-HAUL	3	-14,407	-28.82	3	-9,569	-19.14
PIT-PUMP	2	-4,164	-8.33	1	0	0.00
LAG-HAUL	4	-8,674	-17.35	4	-4,594	-9.19
LAG-PUMP	1	0	0.00	2	-221	-0.44
1,000 HEAD						
TANK-HAUL	5	-58,005	-58.01	5	-51,894	-51.89
PIT-HAUL	3	-21,191	-21.19	4	-15,297	-15.30
PIT-PUMP	2	-4,544	-4.54	1	0	0.00
LAGOON-HAUL	4	-9,149	-9.15	3	-5,366	-5.37
LAGOON-PUMP	1	0	0.00	2	-519	-0.52
2,000 HEAD						
PIT-PUMP	2	-5,126	-2.56	1	0	0.00
LAGOON-HAUL	3	-10,096	-5.04	3	-6,526	-3.26
LAGOON-PUMP	1	0	0.00	2	-731	-0.37
3,000 HEAD						
PIT-PUMP	2	-5,548	-1.85	2	-8,441	-2.81
LAGOON-HAUL	3	-11,044	-3.68			
LAGOON-PUMP	1	0	0.00	1	0	0.00
4,000 HEAD						
PIT-PUMP	2	-12,981	-3.25	2	-18,404	-4.60
LAGOON-HAUL	3	-13,232	-3.30			
LAGOON-PUMP	1	0	0.00	1	0	0.00
5,000 HEAD						
PIT-PUMP	2	-21,542	-4.31	2	-27,173	-5.43
LAGOON-PUMP	1	0	0.00	1	0	0.00
6,000 HEAD						
PIT-PUMP	2	-34,711	-5.79	2	-34,993	-5.83
LAGOON-PUMP	1	0	0.00	1	0	0.00
7,000 HEAD						
PIT-PUMP	2	-43,859	-6.27	2	-42,825	-6.12
LAGOON-PUMP	1	0	0.00	1	0	0.00
8,000 HEAD						
PIT-PUMP	2	-50,566	-6.32	2	-50,644	-6.33
LAGOON-PUMP	1	0	0.00	1	0	0.00
9,000 HEAD						
PIT-PUMP	2	-58,669	-6.52	2	-57,049	-6.34
LAGOON-PUMP	1	0	0.00	1	0	0.00
10,000 HEAD						
PIT-PUMP	2	-66,710	-6.67	2	-63,451	-6.35
LAGOON-PUMP	1	0	0.00	1	0	0.00

6.5 Optimal Size of Swine Production-Waste Management When Off-farm Waste Disposal is not Available

In planning the optimal waste management strategy, consider that representative swine producers in Texas and Seminole counties select the maximum size of finishing operation (up to a maximum of 10,000 head) that can be established on irrigated cropland of 256 acres and on irrigated forage land of 200 acres, respectively, if off-farm waste disposal is not available. Given the resource endowment and current environmental regulations, optimal waste management strategies including operating size and crop selection for each alternative system can be obtained from the linear programming results. The basic information for the parameters in formulating the LP model used the regression equation of total annual costs for waste handling which was drawn from the process of the MILP solution (Refer to Table 6-6).

In the case of Texas county, the optimal objective values of each alternative system ranged from $18,089 associated with a 0 head for the TANK-HAUL system to $117,278 with 6,645 head in the LAGOON-PUMP system, as shown in Table 6-10.[40] As expected, the TANK-HAUL system was found to be not combined with a swine production system since the waste handling cost using this system was very high. The LAGOON-PUMP system was found to have the largest profitability with a 6,645 head operation. The PIT-PUMP system appeared to have the second largest profitability with 3,322 head operation. These results are consistent with the results drawn from the mixed integer programming

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[40] The profit with zero swine operation in the TANK-HAUL system was appeared to be $18,089. This profit was drawn from income of corn produced in 256 irrigated land.

model. In the crop production system, wheat was not competitive except for the LAGOON-HAUL system because of a combination of lower returns and lower nutrient requirements than those of corn.

Similarly, in Seminole county, the optimal objective values of each alternative system ranged from $10,219 associated with 0 head operation in the TANK-HAUL system to $57,166 with 4,192 head in the LAGOON-PUMP system, as shown in

Table 6-10 Optimal Size of Swine Production and Waste Management Practices in Texas County

Selected system	Overall profitability	Resource allocation Herd size	Cropland[1]	Selected crop-yield	Buying fertilizer[2] Nitrogen	Phosphorus
	--- dollar -	--- head --	-- acre ---		------- pound	------------
TANK-HAUL	18,089	0	256 (97)	Corn-High	71,680 (0.250)	47,846 (0.110)
PIT-HAUL	12,923	808	256 (97)	Corn-High	61,803 (0.250)	36,210 (0.110)
PIT-PUMP	59,336	3,322	256 (271)	Corn-High	40,280 (0.250)	0 (-0.965)
LAGOON-HAUL	33,701	2,051	256 (207)	Corn-High	56,637 (0.250)	33,077 (0.110)
LAGOON-PUMP	117,278	6,645	256 (491)	Corn-High	34,001 (0.250)	0 (-2.093)

1) The figures of the parenthesis in this column represent the shadow prices of the crop land.

2) The figures of the parenthesis in these column represent the shadow prices of the manure nutrients.

in Table 6-11. The TANK-HAUL system with a 0 head operation resulted in negative profitability. This result indicates that the TANK-HAUL system should not be applied to a swine waste handling system in Seminole county due to a negative profitability. This result also implies that the Bermuda grass production has a negative return without combining a manure nutrient supply and irrigation in the animal production system. Bermuda grass appeared to be a negative net return forage crop produced from a sprinkler irrigated area in Southwest Oklahoma (Oklahoma Cooperative Extension Service, 1995). The LAGOON-PUMP system was found to be the most profitable waste handling system

Table 6-11 Optimal Size of Swine Production and Waste Management Practices in Seminole County

Selected system	Overall profitability	Resource Allocation Herd size	Cropland[a]	Selected crop-yield	Buying fertilizer[b] Nitrogen	Phosphorus
	--- dollar -	--- head --	-- acre ---		------- pound	----------
TANK-HAUL	-10,219	0	200 (21)	Bermuda-Med	28,218 (0.250)	18,878 (0.110)
PIT-HAUL	-6,857	634	200 (21)	Bermuda-Med	20,458 (0.250)	9,735 (0.110)
PIT-PUMP	25,753	2,096	200 (177)	Bermuda-High	25,557 (0.250)	0 (-0.942)
LAGOON-HAUL	11,582	1,523	200 (21)	Bermuda-Med	17,043 (0.250)	7,906 (0.110)
LAGOON-PUMP	57,166	4,192	200 (339)	Bermuda-High	21,596 (0.250)	0 (-2.017)

[a] The figures in the parentheses in this column represent the shadow prices of the crop land.

[b] The figures in the parentheses in these columns represent the shadow prices of the manure nutrients.

with a 4,192 head operation. The PIT-PUMP system with a 2,096 head operation appeared to be a second best handling system in Seminole county.

In calculating the marginal value of land, the value of crop land is derived from crop production plus its value for swine waste disposal. For example, for the LAGOON-PUMP system in Texas county, the marginal land value of $491 means that an additional acre of land would contribute $491 to profitability. In Seminole county, the marginal land value for the LAGOON-PUMP system was $339 which is the value of contribution to the profitability from an incremental acre of land. In the same way, the shadow prices of manure nutrient presented in the table represent the amount which the objective function would be increased or decreased by if the constraints were relaxed by one unit. All the system showed negative shadow price on phosphorus. The shadow price of fertilizer nutrients decreased dramatically as excess nutrients increase. For example, in the case of the PIT-HAUL system in Texas county, a swine producer could pay up to $0.11 to buy one more pound of phosphorus which would allow the swine enterprise to expand. However, with the LAGOON-PUMP system, the swine producer could pay up to $2.02 to dispose of one more pound of phosphorus. This amount of value could be interpreted as a disposal cost for excess phosphorus. The LP model utilized here has indicated the least cost of compliance with nutrient restrictions with the assumption of not exporting swine manure. Spreading on a neighbor's land, purchase or rental of additional land for manure disposal, and payment to contractors for hauling away excess manure are all costly but effective adjustments that swine producers may make. The integrated decision model developed here used the custom hauling cost for excess nutrient disposal.

6.6 Impacts of Additional Environmental Regulations on the Swine CAFOs

The economic impact of environmental regulations on a swine operation depends upon the production technology and waste management systems. The economic analysis of changes in the regulations and programs can be analyzed using sensitivity analysis by changing the appropriate input parameters in the integrated decision model. To simulate the change of scenario, one model run at a time for each change. All other parameters are maintained unchanged from the benchmark model.

6.6.1 Impacts of Environmental Regulations on Minimum Acreage Requirements

The Indiana Confined Feeding Control Law limits manure application rates to a maximum of 150 pounds of available nitrogen/acre/year. The producer must provide the minimum number of acres to spread the waste from the proposed swine operation (Indiana Department of Environmental Management, 1996). Depending on the type of crop grown and initial soil fertility, the acreage required for proper utilization of nitrogen may vary under the Indiana regulations. Table 6-12 presents the maximum animal capacity per acre of land. The maximum capacity for finishing pigs is 17 head per acre for a liquid handling system and 65 head per acre for a lagoon system. If the Indiana requirement is applied to the Texas county example (based on 256 acres of irrigated corn), the maximum herd size would be 8,192 head for a tank or pit system and 30,976 head for a lagoon system. The animal maximum size of finishing operation in Seminole county (based on 200 acres for irrigated Bermuda grass) would be 4,600 head for a tank or pit system and 17,400 head for a lagoon system. The adoption of nitrogen based restrictions like those in Indiana for a lagoon system. The adoption of nitrogen based restrictions like those in Indiana would not have much effect on swine production in either study area if producers had the acreage assumed in this study and used LAGOON-PUMP systems.

Table 6-12 Animal Capacity Requirement for Available Acreage

	Waste Management System	
	Liquid	Lagoon
	---------------- head ----------------	
Indiana Regulation -150 lb Available N/acre/year[a]		
Growing/Finishing Pigs per acre	17	65
Texas County - 280 lb Available N/acre/year[a]		
Growing/Finishing Pigs per acre	32	121
256 acre for irrigated corn production	8,192	30,976
Seminole County - 200 lb Available N/acre/year[a]		
Growing/Finishing Pigs per acre	23	87
200 acre for irrigated Bermuda production	4,600	17,400

[a] The calculation of the maximum capacity of animal per acre is based only on the nitrogen uptake level. There are no phosphorus restrictions in land application. The figures for available nitrogen represent the nitrogen uptake level related to crop production

6.6.2 Limiting Waste Application Rate to Crop Uptake of Nitrogen Only

As mentioned in Chapter 3, the Oklahoma rule in most cases limits application rates to nitrogen uptake by the crop. Targeting nitrogen versus phosphorus for land application restriction is an interesting example in the environmental regulations on swine production operations. Major crops such as corn and wheat need relatively more nitrogen than phosphorus. Swine manure has a relatively high phosphorus content. The application of swine waste to satisfy crop nitrogen needs usually implies that phosphorus is supplied in excess of crop needs. To restrict only nitrogen loading to cropland ignores the likely excess phosphorus application.

In Texas county as shown in Table 6-13, the LAGOON-PUMP system remained the most profitable system for each size of operation under restrictions that limit nitrogen loading only. The changes from phosphorus to nitrogen restrictions did not affect the profitability of operations with less than 3,000 head for the PIT-PUMP system and with less than 6,000 head for the LAGOON-PUMP system. The differences in profitability between regulations that limit nutrient applications to crop use of nitrogen and phosphorus and those which limit application rates to crop use of nitrogen only are presented in Table 6-14. The nitrogen only restriction is less restrictive and would increase private profitability over that allowed by a restriction on phosphorus loading. The profitability of the PIT-PUMP system under nitrogen only loading restriction would be increased $6,105 for a 4,000 head and $50,603 for a 10,000 head operation over the returns that could be obtained if phosphorus loadings were also limited. In contrast, the profitability of the LAGOON-PUMP system would increase $1,599 for a 7,000 head operation and $15,120 for a 10,000 head operation.

In Seminole county (Table 6-15), the PIT-PUMP system remained the most profitable system on operations less than 2,000 head. The LAGOON-PUMP system remained the most profitable system for operations over 3,000 head. Relaxing the

Table 6-13 Profitability of Selected Waste Management Systems When Only Nitrogen Applications are Limited to Crop Uptake for Texas County

Size of operation	Overall profitability	Annual cost Total	Annual cost Per pig space	Fertilizer cost	Additional land	Rank	Selected systems
-- head --	dollar				--acre----		
500	21,118	6,306	12.61	22,078	0	1	LAGOON-PUMP
	16,954	11,339	22.68	21,210	0	2	PIT-PUMP
1,000	28,069	8,690	8.69	20,974	0	1	LAGOON-PUMP
	23,525	14,971	14.97	19,237	0	2	PIT-PUMP
2,000	42,824	12,604	6.30	18,764	0	1	LAGOON-PUMP
	37,697	21,205	10.60	15,290	0	2	PIT-PUMP
3,000	58,459	15,639	5.21	16,555	0	1	LAGOON-PUMP
	52,911	26,398	8.80	11,344	0	2	PIT-PUMP
4,000	74,933	17,834	4.46	14,345	0	1	LAGOON-PUMP
	68,055	**30,587**	**7.65**	**8,470**	**0**	**2**	**PIT-PUMP**
5,000	90,141	21,296	4.26	12,136	0	1	LAGOON-PUMP
	83,692	33,773	6.75	6,108	0	2	PIT-PUMP
6,000	107,876	22,230	3.71	9,926	0	1	LAGOON-PUMP
	97,301	38,986	6.50	3,745	0	2	PIT-PUMP
7,000	**123,223**	**25,272**	**3.61**	**7,998**	**0**	**1**	**LAGOON-PUMP**
	110,911	44,199	6.31	1,383	0	2	PIT-PUMP
8,000	137,983	28,389	3.55	6,580	0	1	LAGOON-PUMP
	121,828	49,486	6.19	0	14	2	PIT-PUMP
9,000	152,819	31,431	3.49	5,163	0	1	LAGOON-PUMP
	129,121	54,699	6.08	0	48	2	PIT-PUMP
10,000	167,654	34,473	3.45	3,745	0	1	LAGOON-PUMP
	136,426	59,911	5.99	0	82	2	PIT-PUMP

Note: The bold figures represent a turning point of increasing profitability under restriction on nitrogen only application compared with restrictions on both nitrogen and phosphorus.

Table 6-14 Profitability of Selected Waste Management Systems with Loading Restrictions on Nitrogen and Phosphorus and with Loading Restrictions Only on Nitrogen for Texas County

Head System	Rank	Profitability: With nitrogen and phosphorus restricted	Profitability: With restriction on nitrogen only	Difference in profitability
		----- dollar/year -----		
4,000 Head				
LAGOON-PUMP	1	74,933	74,933	0
PIT-PUMP	2	61,950	68,055	6,105
5,000 Head				
LAGOON-PUMP	1	90,141	90,141	0
PIT-PUMP	2	68,599	83,692	15,093
7,000 Head				
LAGOON-PUMP	1	121,624	123,223	1,599
PIT-PUMP	2	77,765	110,911	33,146
10,000 Head				
LAGOON-PUMP	1	152,534	167,654	15,120
PIT-PUMP	2	85,823	136,426	50,603

restriction on phosphorus applications increased the profitability of operations over 3,000 head for the PIT-PUMP system and over 5,000 head for the LAGOON-PUMP system. The differences in profitability between restricting nitrogen and phosphorus versus restricting nitrogen only are presented in Table 6-16. The profitability of the PIT-PUMP system increased by $8,189 for a 3,000 head operation and $51,000 for a 10,000 head operation as the phosphorus regulation was relaxed. The profitability of the LAGOON-PUMP system increased by $3,661 for a 5,000 head operation and $21,558 for a 10,000 head operation.

6.6.3 Regulation on Covering Outside Storage Structures

New environmental regulations for control of nuisance odor in Iowa could possibly require that all outdoor manure storage facilities. The regulation includes both earthen basin and anaerobic lagoons. Outside storage structures can be covered in two ways (Babcock, Fleming, and Bundy, 1997). The first way is to cover them with industrial-grade plastic sheeting supported by polystyrene floats. Another alternative is to cover the outside storage with chopped straw. This method is less expensive but increases the problems of sludge buildup. In this study it is assumed the covering material would be a plastic cover supported by polystyrene floats. The cost of covering a lagoon or outside pit is proportionate to the surface area to be covered, which in turn depends on the size of a lagoon or a pit and the amount of waste generated. The plastic cover is estimated to cost $2.75 per square foot and has an expected life of 10 years (Babcock, Fleming, and Bundy, 1997). Using this unit cost per square foot, the costs of covering outside structures were

Table 6-15 Profitability of Selected Waste Management Systems When Only Nitrogen Applications are Limited to Crop Uptake for Seminole County

Size of operation	Overall profitability	Annual cost Total	Annual cost Per pig space	Fertilizer cost	Additional land	Rank	Selected systems
-- head	----------------------	dollar	----------------------		--acre----		
500	2,003	11,765	23.53	12,688	0	1	PIT-PUMP
	1,782	11,117	22.23	13,557	0	2	LAGOON-PUMP
1,000	8,912	15,059	15.06	10,715	0	1	PIT-PUMP
	8,393	13,841	13.84	12,452	0	2	LAGOON-PUMP
2,000	23,270	21,107	10.55	6,769	0	1	PIT-PUMP
	22,539	18,364	9.18	10,243	0	2	LAGOON-PUMP
3,000	37,622	21,951	7.32	8,033	0	1	LAGOON-PUMP
	37,370	**25,982**	**8.66**	**4,254**	**0**	**2**	**PIT-PUMP**
4,000	53,604	24,638	6.16	5,824	0	1	LAGOON-PUMP
	52,453	29,722	7.43	1,892	0	2	PIT-PUMP
5,000	**69,845**	**26,427**	**5.29**	**4,254**	**0**	**1**	**LAGOON-PUMP**
	64,535	35,200	7.04	0	8	2	PIT-PUMP
6,000	76,500	30.032	5.01	2,837	0	1	LAGOON-PUMP
	71,545	40,677	6.78	0	50	2	PIT-PUMP
7,000	98,390	33,637	4.81	1,419	0	1	LAGOON-PUMP
	78,562	46,155	6.59	0	92	2	PIT-PUMP
8,000	112,587	37,318	4.66	2	0	1	LAGOON-PUMP
	85,497	51,707	2.98	0	133	2	PIT-PUMP
9,000	123,106	40,923	4.55	0	24	1	LAGOON-PUMP
	92,505	57,185	6.35	0	175	2	PIT-PUMP
10,000	133,533	44,529	4.45	0	50	1	LAGOON-PUMP
	99,524	62,662	6.27	0	216	2	PIT-PUMP

Note: The bold figures represent a turning point of increasing profitability under restriction on nitrogen only application compared with restrictions on both nitrogen and phosphorus.

Table 6-16 Profitability of Selected Waste Management Systems with Loading Restrictions on Nitrogen and Phosphorus and with Loading Restriction on Nitrogen Only for Seminole County

Head	System	Rank	Profitability: With nitrogen and phosphorus restricted	Profitability: With restriction on nitrogen only	Difference in profitability
			---------- dollar/year	----------	----------
3,000 Head					
	LAGOON-PUMP	1	37,622	37,622	0
	PIT-PUMP	2	29,181	37,370	8,189
5,000 Head					
	LAGOON-PUMP	1	66,184	69,845	3,661
	PIT-PUMP	2	39,011	64,535	25,524
7,000 Head					
	LAGOON-PUMP	1	85,665	98,390	12,725
	PIT-PUMP	2	42,841	78,562	35,722
10,000 Head					
	LAGOON-PUMP	1	111,975	133,533	21,558
	PIT-PUMP	2	48,524	99,524	51,000

estimated as shown in Table 6-17.

In Texas county, the annual capital costs of covering an outside pit for a 1,000 head operation and a 10,000 head operation were estimated to be $23,147 and $224,212, respectively. The annual capital costs of covering a lagoon system was estimated to be $20,016 for a 1,000 head operation and $163,979 for 10,000 head. On a per head basis the annual covering cost for a 1,000 head operation would be $23.14 for an outside pit and $20.02 for a lagoon. For a 10,000 head operation, the covering cost per pig space would be $22.42 for an outside pit and $16.40 for a lagoon.

In Seminole county, the costs of covering an outside pit for 1,000 head and 10,000 head operations is estimated to be $23,755 and $225,460, respectively. Similarly, the annual cost of covering a lagoon system is estimated to be $20,608 for a 1,000 head and $116,378 for a 10,000 head operation. In these cases, annual costs for covering per pig space with a 1,000 head operation would be $23.76 for an outside pit and $20.61 for a lagoon. For a 10,000 head operation, the annual covering costs per pig space would be $22.55 for an outside pit and $11.64 for a lagoon.

The LAGOON-PUMP would be the optimal system for all sizes of operations in the Texas county case if regulations required that outside waste storage structures be covered. The annual cost of covering outside storage structures in both study areas was found to be 5 to 8 times higher than the construction cost of each storage structure, as shown in Table 6-17. Requiring that storage be covered would have a substantial negative impact on the profitability of a swine production, as shown in Table 6-18 (Texas county) and Table 6-19 (Seminole county).

Table 6-17 Annualized Capital Costs of Construction and Covering for Waste Storage Structures

Size of operation	Slurry Tank		Earthen Pit		Anaerobic Lagoon	
	Construction	Covering	Construction	Covering	Construction	Covering
	dollar					
Texas County						
500	15,889	0	2,222	11,977	1,779	12,018
1,000	29,668	0	4,283	23,147	3,505	20,016
3,000	84,952	0	10,021	67,828	8,328	52,008
5,000	141,588	0	12,461	112,509	12,120	84,000
7,000	198,223	0	17,039	157,190	14,531	115,992
10,000	283,176	0	24,825	224,212	20,746	163,979
Seminole County						
500	15,889	0	2,615	12,518	2,002	12,509
1,000	29,668	0	4,451	23,755	3,849	20,608
3,000	84,952	0	9,988	68,702	8,986	53,001
5,000	141,588	0	14,155	113,650	11,170	85,395
7,000	198,223	0	19,749	158,597	15,600	117,788
10,000	283,176	0	28,140	225,460	22,245	166,378

Under the regulation on covering outside storage in Texas county, the profitability for a 500 head swine operation with corn production on 256 acres was $7,395 in the LAGOON-PUMP system and $3,633 in the PIT-PUMP system. The profitability rapidly decreased as the size of the operation increased because of increasing annual capital costs. For example, the profitability for a 5,000 head operation was found to be negative $5,774 in the LAGOON-PUMP system and negative $59,155 in the PIT-PUMP system. Thus, imposing a regulation to cover outside waste storage may result in substantial reduction of producer profit. The reduction in profit for the covering regulation in the LAGOON-PUMP system was found to be $13,723 for a 500 head operation and $59,385 for a 5,000 head operation (Table 6-18). Similarly, in Seminole county, the profitability for a 500 head swine operation with Bermuda hay production on 200 acres was negative $11,822 in the LAGOON-PUMP system and negative $11,931 in the PIT-PUMP system, as shown in Table 6-19. The profitability rapidly decreased as the size of operation increased. For example, the profitability for a 5,000 head operation was found to be negative $26,677 in the LAGOON-PUMP system and negative $90,038 in the PIT-PUMP system. The regulation on covering outside storage may results in a huge profitability loss. The difference in profitability with/without regulation on covering a lagoon system was found to be $13,604 for a 500 head operation and $92,861 for a 5,000 head operation.

6.7. Impact of the EQIP Program on Smaller Swine Operations

Swine producers in the study areas are eligible through the EQIP (Environmental Quality Incentive Program) cost-sharing program to be subsidized for a portion of the cost

Table 6-18 Effect on Profitability of a Requirement to Cover Waste Storage Structures in Texas County

Head System	Rank	Profitability: Without regulation	Profitability: With regulation	Difference
		---------- dollar ----------		
500 Head				
LAGOON-PUMP	1	21,118	7,395	-13,723
PIT-PUMP	2	16,954	3,633	-13,321
1,000 Head				
LAGOON-PUMP	1	28,069	5,214	-22,855
PIT-PUMP	2	23,525	-2,511	-26,036
3,000 Head				
LAGOON-PUMP	1	58,459	-926	-59,385
PIT-PUMP	2	52,911	-23,984	-76,895
5,000 Head				
LAGOON-PUMP	1	90,141	-5,774	-95,915
PIT-PUMP	2	68,599	-59,155	-127,754
7,000 Head				
LAGOON-PUMP	1	121,624	-10,813	-132,437
PIT-PUMP	2	77,765	-100,848	-178,613
10,000 Head				
LAGOON-PUMP	1	152,534	-34,705	-187,239
PIT-PUMP	2	85,823	-169,079	-254,902

Table 6-19 Effect on Profitability of a Requirement to Cover Waste Storage Structures in Seminole County

Head System	Rank	Profitability: Without regulation	Profitability: With regulation	Difference
		dollar		
500 Head				
PIT-PUMP	1	2,003	-11,931	-13,931
LAGOON-PUMP	2	1,782	-11,822	-13,604
1,000 Head				
PIT-PUMP	1	8,912	-17,810	-26,722
LAGOON-PUMP	2	8,393	-14,018	-22,411
3,000 Head				
LAGOON-PUMP	1	37,622	-20,015	-57,637
PIT-PUMP	2	29,181	-48,705	-77,886
5,000 Head				
LAGOON-PUMP	1	66,184	-26,677	-92,861
PIT-PUMP	2	39,011	-90,038	-129,049
7,000 Head				
LAGOON-PUMP	1	85,665	-42,432	-128,097
PIT-PUMP	2	42,841	-137,371	-180,212
10,000 Head				
LAGOON-PUMP	1	111,975	-68,949	-180,924
PIT-PUMP	2	48,524	-208,433	-256,958

of construction of waste storage facilities and equipment (Refer to Table 3-2). As mentioned in Chapter 3, the cost sharing amount is limited to 75 percent of costs for a waste storage facility (slurry tank, earthen pit, or lagoon) up to a maximum of $10,000. Total cost-share and incentive payments are limited to $10,000 per person per year and $50,000 over the length of the contract. The cost sharing fund from the CCC (Commodity Credit Corporation) cannot be used for pumping equipment, buildings, spreading equipment, or spreading swine wastes on the land. Swine producers with 1,000 animal units (6,700 head of 150 pound finishing pigs) or less are eligible for financial assistance for animal waste management facilities (USDA NRCS OK, 1997). The maximum rate of cost sharing for swine waste management facilities under the EQIP is presented in Table 3-2 in Chapter 3. Based on the maximum rate of cost sharing, the available rates in the study areas are estimated as shown in Table 6-20. For an operation consisting of 500 head, the cost share support in Texas county ranged from 5.8 percent of the tank construction cost to 41.4 percent of the pit construction cost. In Seminole county, the cost share support ranged from 5.8 percent of the tank construction cost to 35.2 percent of the pit construction cost. However, the cost-sharing rate for a 6,000 head operation ranged from 0.5 percent of the tank construction cost to 6.2 percent of the pit construction cost in Texas county. The rate of cost sharing is higher for smaller size operations due to a lump sum subsidy while a large size operation has a low sharing rate. The economic effect of the EQIP program on swine waste handling costs can be easily analyzed. The amount of cost sharing is subtracted from total investment costs of the items eligible. The annual cost saving for eligible operations in either study area ranged from about $1,300 for a tank system to $1,100 for a pit and a lagoon system, as shown in Table 6-21. For the smaller operations of 500 and 1,000 head, the average annual cost of swine waste management could be reduced by $2.67 per pig space for a tank system and $1.12 per pig space for a pit and a lagoon system, respectively. However, for operations containing over 4,000 head, the average annual cost of swine waste management would be reduced by only about $0.30 per pig space for a tank system and about $0.25 for a pit and a lagoon system. For an operation of less than 2,000 head of finishing pigs, the cost-sharing program in the EQIP would reduce total waste management costs for a lagoon facility by nine percent. The result illustrates that the cost-sharing program would provide marginal relief for small sizes of swine operations.

Table 6-20 Feasible Rate of Cost-Sharing for Storage Construction in the EQIP Program

Size of operation	Slurry Tank		Earthen Pit		Anaerobic Lagoon	
	Texas	Seminole	Texas	Seminole	Texas	Seminole
	percent					
500	5.8	5.8	41.4	35.2	51.7	45.9
1,000	3.1	3.1	21.5	20.7	26.3	23.9
2,000	1.6	1.6	12.2	12.0	14.7	13.6
3,000	1.1	1.1	9.2	9.2	11.0	10.2
4,000	0.8	0.8	7.9	7.6	9.5	8.8
5,000	0.6	0.6	7.4	6.5	7.6	8.2
6,000	0.5	0.5	6.2	5.4	7.4	6.9

Table 6-21 Amount of Cost Saving from EQIP Program for Swine Waste Management System

Size of operation	Tank System Total	Tank System Average	Pit System Total	Pit System Average	Lagoon System Total	Lagoon System Average
	----	----	---- dollar ----	----	----	----
Texas County						
500	1,335	2.67	1,377	2.75	1,120	2.24
1,000	1,316	1.32	1,120	1.12	1,122	1.12
2,000	1,315	0.65	1,119	0.56	1,122	0.56
3,000	1,316	0.44	1,172	0.39	1,115	0.37
4,000	1,316	0.33	1,122	0.28	1,112	0.28
5,000	1,315	0.26	1,118	0.22	1,121	0.22
6,000	1,354	0.23	1,123	0.19	1,123	0.19
Seminole County						
500	1,336	2.67	1,188	2.38	1,120	2.24
1,000	1,315	1.32	1,122	1.13	1,119	1.12
2,000	1,308	0.65	1,119	0.56	1,112	0.56
3,000	1,308	0.44	1,120	0.37	1,115	0.37
4,000	1,316	0.33	1,122	0.28	1,122	0.28
5,000	1,315	0.26	1,118	0.22	1,121	0.22
6,000	1,354	0.23	1,122	0.19	1,123	0.19

CHAPTER VII

SUMMARY, CONCLUSIONS AND LIMITATIONS

7.1 Summary of the Study

The objectives of this study were to evaluate the economics of alternative swine waste management systems and to determine the optimal waste management strategy that maximized a representative swine producer's profitability from production while managing swine waste in a manner that met environmental regulations. The objectives were accomplished through the use of an integrated mixed integer decision model. The model was used to determine the most profitable swine production and waste management system for representative producers in Texas and Seminole counties of Oklahoma. The analytical results can be summarized as follows:

1. Waste storage structures used with pit recharge systems with reasonable odor control must be designed to handle 2.70 cu.ft. of water per pig space per day, provide 120 days of waste storage and have an additional safety volume if the structures are open. The average volume of waste storage required per finishing pig (150 pound) in Texas county was 320 cu.ft. for a slurry tank system, 460 cu.ft. for a pit system, and 380 cu.ft. for a lagoon system. In Seminole county, the average volume of waste storage per finishing pig was 320 cu.ft. for a tank system, 515 cu.ft. for a pit system, and 410 cu.ft. for a lagoon system. The capacity required for waste storage is greater in Seminole county than in Texas county because the former has higher net precipitation.

2. The tank storage-tractor hauling system was the highest operating and investment cost system among all systems in both study areas. The lowest operating and

investment cost system was the lagoon system which could be utilized with existing a center pivot irrigation systems in Texas county and with traveling gun irrigation in Seminole county. The annual total cost of waste handling for the 1,000 head operation in Texas county ranged from \$8,690 (or \$8.69 per pig space) for the lagoon with an irrigation system to \$71,157 (or \$71.16 per pig space) for the tank with a hauling system. In Seminole county, annual total cost of waste handling for a 1,000 head capacity system ranged from \$13,841 (or \$13.84 per pig space) for the lagoon system with a traveling gun irrigation to \$69,677 (\$69.68 per pig space) for the tank system with a hauling method. The annual total cost per pig space for all the waste treatment systems declined sharply as herd size increased. Economies of size in swine waste handling systems exist.

3. Under the benchmark model, the annual overall profitability with the lagoon-center pivot irrigation system ranged from \$21,118 (or \$42.24 per pig space) to \$152,384 (or \$15.24 per pig space) for the 500 and 10,000 head operations, respectively. Total profit for the pit-traveling gun ranged from \$16,954 (or \$33.91 per pig space) to \$85,823 (or \$8.58 per pig space) for the 500 and 10,000 operations, respectively. The tank and pit systems, where the waste was hauled by a tractor pulled tanks, were considered not feasible because of their high labor requirements when the size of operation exceed 2,000 head. The pit system with a traveling gun irrigation in Seminole county was the most profitable system for operations with less than 2,000 head. However, it was only \$221 more profitable than the lagoon system with a traveling gun irrigation for a 500 head operation. The lagoon system with a traveling gun irrigation was the most profitable for operations over 3,000 head.

4. The lack of sufficient land for waste disposal severely limits the maximum size of operation. This was illustrated by the examples when the producer had only the 256 irrigated acres in Texas county or the 200 acres of irrigated Bermuda grass in Seminole county with no opportunity for offsite waste disposal. The lagoon system with pivot irrigation in Texas county was found to have the largest profitability with maximum herd size of 6,645 head. The pit system with a traveling gun irrigation was the second most profitable with a maximum herd size of 3,322 head. Similarly, the lagoon system with a traveling gun irrigation in Seminole county was the most profitable system with a 4,192 head operation while the pit system with a traveling gun irrigation was the second most profitable with a maximum of 2,096 head.

5. Adoption of rules which limit the number of animals per acre of land available for waste disposal have less impact on producers with lagoon systems than on producers with pit storage systems.

6. In Texas county, the change from a restriction on amount of phosphorus applied to a restriction on only the amount of nitrogen applied would not increase the profitability of a pit system with 3,000 head or less or the profitability of lagoon system with less than 6,000 head. The profitability of the pit system with a traveling gun would increase by $6,105 for a 4,000 head operation and by $50,603 for a 10,000 head operation. In contrast, the profitability of the lagoon-pivot system would increase by $1,599 (or $0.23 per pig space) for a 7,000 head operation and by only $15,120 (or $1.51 per pig space) for a 10,000 operation. In Seminole county, the pit-traveling gun irrigation system remained the most profitable system for operations with less than 2,000 head. The

lagoon-traveling gun irrigation system remained the most profitable system for operations with more than 3,000 head. The profitability of the pit system with a traveling gun irrigation increased by $8,189 for the 3,000 head operation and $51,000 for the 10,000 head operation when the phosphorus regulation was relaxed. The profitability of the lagoon with a traveling gun irrigation increased by $3,661 (or $0.73 per pig space) for a 5,000 head operation and $21,558 (or $2.16 per pig space) for a 10,000 operation when the phosphorus restriction was relaxed.

7. The annual cost of covering outside storage structures with a durable plastic cover supported by polystyrene floats in both study areas was found to be 5 to 8 times higher than the initial construction cost of each storage structure. Thus, imposing a regulation to cover outside waste storage would result in a substantial reduction of the producer's profit unless cheaper methods can be found. The difference in profitability with and without a regulation to cover the lagoon system in Texas county was found to be $13,723 (or $27.44 per pig space) for a 500 head operation and $95,919 (or $19.18 per pig space) for a 5,000 head operation. Similarly , the difference in profitability with and without a regulation which requires that lagoon systems covered in Seminole county was found to be $13,604 (or $27.20 per pig space) for a 500 head operation and $92,861 (or 18.57 per pig space) for a 5,000 head operation.

8. Swine producers in the study areas are with less than 6,700 head eligible for the cost-sharing assistance through the Environmental Quality Incentive Program. Producers may receive up to 75 percent of the cost of waste handling facilities up to a maximum of $10,000 per person per year. Swine producers with 1,000 animal units

(6,700 head of 150 pound finishing pigs) or less are eligible for financial assistance to purchase animal waste management facilities. Under the Environmental Quality Incentive Program, the annual cost saving for eligible operations in either study area ranged from about $1,300 for a tank system to $1,100 for a pit and a lagoon system. For the smaller operations of 500 head and 1,000 head, the average annual cost of swine waste management could be reduced by $2.67 per pig space for a tank system and $1.12 per pig space for a pit and a lagoon system, respectively. For an operation with less than 2,000 head of finishing pigs, the cost-sharing support in the Environmental Quality Incentive Program would reduce total waste management costs for a lagoon facility by nine percent.

7.2 Concluding Remarks

The integrated decision model developed for this study was used to evaluate the costs and returns from alternative swine waste management systems under various environmental policies by altering restrictions on nutrient applications, and storage volume. The following conclusions can be made:

1. Estimation of the engineering costs for a swine waste management system is an essential part of the planning and evaluation process. The data generated by the economic engineering approach can be used in a mixed integer programming model.

2. There is no single best or optimal waste management system for all sizes and types of operations. In general, the use of the lagoon to store and the use of an irrigation system to spread swine waste required less energy and labor and was more cost effective than were the tank-hauling, pit-hauling, or lagoon-hauling systems.

3. For all manure handling systems the annual cost per animal decreased as the herd size increased up to the maximum of 10,000 head considered in this study.

4. Restrictions that limit nitrogen to plant uptake are less restrictive and would increase private returns over restrictions that would limit phosphorus application to plant uptake. Imposing a regulation to cover outside storage would result in substantial reduction of swine producer profits if producers were forced to rely on plastic covers.

5. For smaller operations of less than 2,000 head, waste handling costs were more burdensome on a per animal basis than for larger operations. The EQIP program can provide marginal relief to producers with 1,000 head of finishing pigs or less to partially offset the high cost per animal for waste storage.

This research contributes to the development of a planning model to determine the optimal investment in swine production and waste management systems under current environmental regulations. The results of this research can provide area specific information to swine producers, environmental planners, and regulators about the economic impacts of changes in swine waste management technologies under current and possible future environmental regulations.

A region's competitive position in the swine industry is impacted by how well that region can manage its waste handling problems. The innovation of waste management technologies has the potential to shift advantages to one region at the expense of another. The ability to select optimal waste management systems as enforcement of environmental regulations may strongly influence both regional environmental quality and the future direction of the swine industry in Oklahoma.

7.3 Limitations of the Study

This analysis does provide new insights into swine waste management and related environmental regulations. However, as in any mathematical programming approach, there are several factors that must be addressed. Assumptions and limitations must be considered in interpreting the results. Results can be influenced by the reactions of different soils, the variable nutrient content of swine waste, and changes in factors such as dilution water to reduce air pollution. The results are strictly applicable only to the situations outlined.

Managerial decision making typically involves the consideration of a number of goals that cannot be aggregated into a single criterion to be used as a performance measure for ranking alternatives. The selection of a swine waste management system is an example of such a decision problem. The swine producer's capital investment costs and annual operating expenses are an important criteria in the selection of an appropriate waste management system. However, other factors such as additional environmental quality criteria and the operator's risk attitude are also important.

Finally, only a partial benefit-cost analysis of the new environmental regulations and the Environmental Quality Incentive Program was conducted. The benefits from reducing nutrient runoff and/or leaching and from reducing nuisance odors were outside the scope of this study. This study helps estimate the economic effects of regulations on swine producers but this is only one part of a complete benefit-cost analysis. The economic analysis in this study considers only quantifiable factors in selecting a waste management system.

7.4 Implications for Further Study

Considerable research has been completed to assist in selecting optimal swine waste management systems. Economic studies of waste management systems rely heavily on other disciplines for parameters for the analytical model. Information related to water quality, nutrient loss, nutrient application rates on expected crop yield, the design for storage structures and application systems, and the corresponding economic analysis require information from the fields of agricultural engineering, agronomy, animal science, and agricultural economics. Although many disciplines have already become involved in improving swine waste handling, further study is encouraged within the context of a multi-disciplinary framework.

In the areas of engineering and agronomy, monitoring studies on selected waste handling systems over time assessing location, quantity, and cause of manure nutrient loss and the effects of the nutrients on pollution and crop response are needed in order to more accurately evaluate various waste handling systems. Objective measurement of nuisance odor caused by swine production units has not been established so far. Therefore, developing a technique for quantifying odor intensity and frequency is also needed to consider air quality problems in handling swine waste.

The mathematical programming framework used in this study did not include consideration of the decision makers' risk attitude in the model. An approach without considering risk factors is reasonable only when information on weather and soil are known with certainty, crop yields are expected to remain stationary over time and nutrient losses to the environment are not subject to large spikes. Methods such as chance constrained programming could incorporate these risk factors. It would be useful for future studies to demonstrate the effect of risk attitudes on selection of a waste management system. The integrated decision model developed in this study did not consider benefits of waste management on such non-monetary factors as water quality or producers' preference. These factors could be incorporated in future efforts through some kind of multi-attribute objective function.

To gain a better insight into the transportation problem of swine waste on a regional level, a spatial equilibrium or a decision support system could be developed. Additional research using dynamic models to estimate nutrient runoff, soil erosion, and changes in water quality could provide insight into the complexity of the issue and the policies most applicable.

Finally, development of the integrated decision model in this study was designed to analyze animal waste management, for swine operations in two areas of Oklahoma. With minor adjustments, the integrated decision model could be expanded to other states, other regions, and other animals (e.g., beef cattle, dairy, or poultry).

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APPENDIXES

APPENDIX A--LIST OF EQUIPMENT PRICES FOR SWINE WASTE MANAGEMENT SYSTEM

Table A-1 List of Waste Handling Equipment Prices

Items of Equipment	Unit	Unit price	Purchasing price	Years of life (year)	Source
Storage equipment					
Tank System					
Tank - 42 * 28	$/gal	0.14	40,530	20	A.O. Smith Harvestor (1997)
Tank - 62 * 28	$/gal	0.14	84,139	20	A.O. Smith Harvestor (1997)
Tank - 81 * 28	$/gal	0.13	140,888	20	A.O. Smith Harvestor (1997)
Tank - 101 * 28	$/gal	0.13	208,969	20	A.O. Smith Harvestor (1997)
Tank - 120 * 28	$/gal	0.12	286,110	20	A.O. Smith Harvestor (1997)
Mount pump (100 HP)	each		10,000	7	Amer Appraisal Asso (1995)
Pit System					
Equipment					
Impeller pump agitator (100 HP)	each		7,150	7	Hydro Engineering Inc. (1997)
Hog fence	$/ft	1.25		20	OCES, Enterprise Budget (1995)
Lagoon System					
Excavation and/or embankment	$/cu.yd.	0.94		20	USDA, NRCS-OK (1997)
Equipment					
Congrugated steel pipe	$/d-inch/ ft	1.29		15	USDA, NRCS-OK (1997)
PVC pipe	$/d-inch/ ft	0.86		15	USDA, NRCS-OK (1997)
Clay liner	cu.yd.	1.25		20	USDA, NRCS-OK (1997)
Chopper pump (100 HP)	each		13,000	7	Hydro Engineering Inc (1997)
Application Equipments					
Tractor					
Tractor, 125 HP	each		53,000	7	OCES, Enterprise Budget (1995)
Honey wagon (3,000 gal)	each		19,000	7	OCES, Enterprise Budget (1995)
Injector	each		2,700	7	Hydro Engineering Inc (1997)
Pipes					
PVC pipes				15	
3" PVC	ft	1.57		15	Cox's Thesis (1993)
4" PVC	ft	1.80		15	Cox's Thesis (1993)
6" PVC	ft	2.60		15	Cox's Thesis (1993)
Sludge hose (3.8")	ft	1.77		7	Hydro Engineering Inc (1997)
Irrigation equipment					
Center pivot system					
Pivot type, 160 acre capacity	each		35,000	20	Amer Appraisal Asso (1995)
Traveling Guns					
1180'-3.75 I.D.	each		21,000	7	Cox's Thesis (1993)
Fertilizer Value					
Nitrogen (N)	$/lb	0.25			OCES, Enterprise Budget (1995)
Phosphorus (P2O5)	$/lb	0.11			OCES, Enterprise Budget (1995)
Potasium (K2O)	$/lb	0.09			OCES, Enterprise Budget (1995)
Fuel and Energy					
Gasoline	gal	1.00			OCES, Enterprise Budget (1995)
Disel	gal	0.75			OCES, Enterprise Budget (1995)
Electricity	Kw	0.06			OCES, Enterprise Budget (1995)
Machinery labor	Hr	5.50			OCES, Enterprise Budget (1995)
Livestock labor	Hr	5.50			OCES, Enterprise Budget (1995)
Labor cost	Hr	6.00			OCES, Enterprise Budget (1995)
Tractor cost	Hr	15.00			OCES, Enterprise Budget (1995)

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5) *A.O. Smith Harvestore Products, Inc. (De Kalb, IL,), 1997.*
6) *Hydro Engineering Inc.,(Salt Lake City, UT), 1997.*

APPENDIX B-- ANNUAL CAPITAL COST FACTORS FOR WASTE HANDLING EQUIPMENT AND FACILITIES

Table A-2 Annual Capital Cost Factors for Waste Handling Equipment 1)

Item	Years of life	Annual capital recovery charge 2)	Real Interest rate	Taxes	Insurance	Annual capital cost factor
	---- year	------------------	------------------ percent	------------------	------------------	------------------
Earthen pit	20	0.077	0.045	0.01	0.0050	0.0919
Slurry tank	20	0.077	0.045	0.01	0.0050	0.0919
Anaerobic lagoon	20	0.077	0.045	0.01	0.0050	0.0919
Fencing	20	0.077	0.045	0.01	0.0050	0.0919
Mount pump	7	0.170	0.045	0.01	0.0050	0.1847
Agitator	7	0.170	0.045	0.01	0.0050	0.1847
Chopper pump	7	0.170	0.045	0.01	0.0050	0.1847
Tank wagon	7	0.170	0.045	0.01	0.0053	0.1850
Tractor	7	0.170	0.045	0.01	0.0053	0.1850
Injector	7	0.170	0.045	0.01	0.0053	0.1850
Irrigation pump/motor	12	0.110	0.045	0.01	0.0053	0.1250
Traveling big gun	7	0.170	0.045	0.01	0.0050	0.1847
Center pivot	20	0.077	0.045	0.01	0.0050	0.0919
PVC pipe	15	0.093	0.045	0.01	0.0050	0.1081
Plastic cover for storage 3	10	0.126	0.045	0.01	0.0050	0.1414
Wells and casings 4)	25	0.067	0.045	0.01	0.0050	0.0824

Notes: 1) The data for years of life, taxes, and insurance are drawn from White and Forster (1978) and Drynan et al. (1981).

2) The capital recovery factor was used to substitute depreciation and interest.

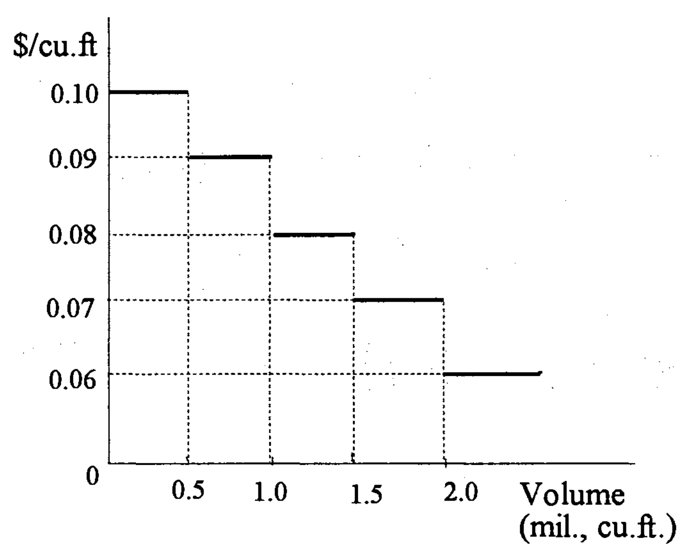
3) The useful life of plastic cover supported by polystyrene floats is drawn from Babcock, Fleming, and Bundy (1997).

4) The information about wells and casing is drawn from Jensen, et al. (1980)

APPENDIX C--ESTIMATION OF LAGOON AND PIT CONSTRUCTION COST

The declining block structure appears to be the predominant form of construction cost for an outside pit or a lagoon. Based on Oklahoma (USDA NRCS OK, 1997), the average cost of lagoon construction was estimated \$2.19/cu.yd. (\$0.08/cu.ft.) which consisted of \$0.94/cu.yd. (\$0.035/cu.ft.) for excavation and/or embankment and \$1.25/cu.yd. (\$0.046/cu.ft.) for the clay liner. The basic rate of the construction cost is assumed to be ranged from \$0.10/cu.ft. to \$0.06/cu.ft. and to be 10 percent declined as the size volume increases by 500,000 cu.ft., until volume equals 2,000,000 cu.ft. (Agpro Inc., 1997). For volumes greater than 2,000,000 cu.ft the rate is assumed to be constant at \$0.06/cu.ft. The basic rate of lagoon construction cost can be described as shown in Figure A-1. The construction cost of an outside pit was estimated in the way as the summing the basic rate of lagoon construction but with the additional fence cost of a perimeter.

Figure A-1 Block Scheme of Lagoon Construction Cost



APPENDIX D--CONFIGURATION OF MAJOR COMPONENTS IN WASTE HANDLING SYSTEMS

Table A-3 Major Components in Waste Handling Systems

Storage System

Slurry Tank	Earthen Pit	Anaerobic Lagoon
· Agitator - 100 HP (3,600 gpm)	· Agitator - 100 HP (3,600 gpm)	· Chopper pump - 100 HP (3,600 gpm)
· Mount pump - 100 HP		

Application System

Hauling System	Pumping System	
	Traveling gun system	Center pivot system
· Honey wagon - 3,000 gal (400 cu.ft.)	· PVC pipe - 1/4 mile (6")	· PVC pipe - 1/4 mile (6")
· Tractor (125 HP) - 1/3 of purchasing price	· Travel gun - 1180'-3.75 ID - 50 HP	
· Injector	· Sludge hose - 660 ft (3.8")	

APPENDIX E--ESTIMATION OF PUMPING COST

The estimation of the horse power required to move a given quantity of waste from storage to a field is the initial step in estimating the cost of waste application by an irrigation system. This is done by determining the flow capacity in gallons per minute (gpm) and the total dynamic head (TDH). Flow capacity is calculated by multiplying the maximum number of sprinkler heads operating at one time by the capacity of the sprinkler. The pressure at the sprinkler for a traveling gun is assumed to be 80 pounds per square inch (psi). The power or pressure necessary to move waste through a PVC pipe (6 inch diameter and 1,320 feet of length) with a friction coefficient of 150 was estimated using the formula by Cox (1993). It was assumed that riser height for traveling gun was 9 feet and that the elevation difference between the pump and the highest point in the crop field was 20 feet. Then, the total dynamic head was calculated as follows:

Sprinkle pressure	=	80 psi	× 2.31	=	184.8	feet
½ of friction loss in lateral line	=	37.5 psi	× 2.31	=	86.6	
Friction loss in main line	=	10.5 psi	× 2.31	=	24.3	
Riser height	=	9.0		=	9.0	
Elevation difference	=	20.0		=	20.0	
Total TDH					324.7	

Using the value of TDH, Brake Horsepower (BHP) for pumping motor can be calculated by:

$$BHP = \frac{[Pump\ Capacity(gpm)] \times [Total Dynamic Head(feet)]}{3{,}960 \times [Pump Efficiency(70\%)] \times [Engine Efficiency(70\%)]}$$

Assuming the sprinkler gun operates at 300 gpm capacity, it would require 50.2 BHP. Thus 50 BHP was used in this study and then the fuel cost was calculated by multiplying the BHP by the conversion factor 0.044 (Bowers, 1987).

Unit Conversion Factors*

Multiply to the right, i.e., cubic feet × 7.5 = gallon

Cubic feet	7.5	gallons
	62.4	pound of water
Gallons	0.134	cubic feet
	8.3	pound of water
Cubic yard	27	cubic feet
Acres	43,560	square feet
	4,840	square yards
Miles	5,280	feet
	1,760	yard
Acre-inch	3,621	cubic feet
	27,154	gallon
	133	tons
Acre-foot	43,560	cubic feet
	325,848	gallons
Acre-inch/hr	450	gpm

* The unit conversion factors for analyzing a swine waste management was drawn from the MWPS (1983) and the USDA SCS (1992).

APPENDIX F--GAMS PROGRAM FOR THE INTEGRATED DECISION MODEL

< Benchmark Model in Texas County for 1,000 Head Operation >

```
$OFFSYMXREF OFFSYMLIST OFFLISTING
OPTION LIMROW=0;
OPTION LIMCOL=0;

$TITLE: SELECTION OF OPTIMAL SWINE WASTE MANAGEMENT SYSTEMS
*/////////////////////////////////////////////////////
* GAMS MILP Program for Selecting the Optimal Swine Waste
*                    Management System in TEXAS COUNTY (BENCHMARK)
* Basic Assumptions: 256 Acreage and 4 month period of stroage structure
*                     2.70 cu.ft./day additional water volume required
*                     for pit recharge finishing house
* Objective function is based on maximizing overall profitabilty
*///////////////////////////////////////////////////////////////////
*************************
* List of Sets
************************
SETS
* Animal Types and Crop Yields
*------------------------------
* Five types of animal are considered in the swine production operations.
  ANIMAL  type of anaimal
        / NURS    nursery pig
          FIN     finishing pig
          GEST    gestating sow
          SOW     sow
          BOAR    baor    /
  CROP    type of crop          / CORN, WHEAT/
  YIELD      yield ability      / LOW, MED, HIGH/
  TIME           time periods   /T01*T12/

* Types of Waste Storage Systems
*---------------------------------------------
  SYS    alternative waste storage system
        / TSYS1   small size of manure  tank1
          TSYS2   medium size of manure tank2
          TSYS3   large size of manure  tank3
          PIT     outside storage pit
          LAG1    anaerobic one stage lagoon - without reciculation
          LAG2    anaerobic one stage lagoon - with reciculation    /

  TANK(SYS)         type of manure tanks      /TSYS1, TSYS2, TSYS3/
  PIT(SYS)          type of pit system        /PIT/
  LAGTYPE(SYS)      type of lagoons           /LAG1, LAG2/
  TANKLAG(SYS)      type of tanks and lagoons /TSYS1, TSYS2, TSYS3, LAG1, LAG2/
  TANKPIT(SYS)      type of tank and pit      /TSYS1, TSYS2, TSYS3, PIT/
  LAGPIT(SYS)       type of lagoons and pit   /LAG1, LAG2, PIT/

* Attributes of Storage Systems
*-----------------------------------
  ATTRIBUTES         attributes of systems
                      /SIZE, CIC, ACC, AMHAUL, VOL, ANNCOST, TS, VS, N,P,K/
  STORATT(ATTRIBUTES) attributes of storage systems
                      / SIZE, CIC, ACC, AMHAUL, N, P/
  LAGELEM(ATTRIBUTES)                          /SIZE, AMHAUL/
  NUTRIENT(ATTRIBUTES) type of nutrient       /N,P/
  SOLID(ATTRIBUTES)    type of manure solid   /TS, VS/

* Types of Land Applcation Systems
*--------------------------------------------
  APPSYS           type of hauling systems
```

```
                  / HSYS1   tank wagon
                    HSYS2   tank wagon with injector
                    HSYS3   tank wagon with vacuum pump and injector
                    IRRTANK tank system with irrigation
                    IRRLAG  lagoon system with irrigation
                    IRRPIT pit system with irrigation /

  HAULSYS(APPSYS) hauling system using honey wagon
                    /HSYS1, HSYS2, HSYS3/
  IRRSYS(APPSYS)  irrigation system
                      /IRRTANK, IRRLAG,IRRPIT/
  IRRTKPIT(APPSYS) irrigation of tank or pit
                      /IRRTANK, IRRPIT/
  IRRLAGPIT(IRRSYS) irrigation of lagoon and pit
                      /IRRLAG, IRRPIT/
  HAULPIT(APPSYS)  haul pit methods
                     /HSYS1, HSYS2, HSYS3/
  HAULTANK(APPSYS)   haul tank methods
                     /HSYS1, HSYS2, HSYS3/
  HAULLAG(APPSYS)  haul lagoon methods
                     /HSYS1, HSYS2, HSYS3/
  HAULTKLAG(APPSYS) wagon for haul tank or lagoon
                     /HSYS1, HSYS2, HSYS3/
  COMBSYS(SYS, APPSYS) combination of alterative storage and hauling systems
                      / (TSYS3, PIT,LAG1).HSYS3,
                         PIT.IRRPIT,
                         LAG1.IRRLAG /;

************************************
* Data for the Model Running
************************************
SCALAR
* Environmental Regulatory Parameters
*-------------------------------------
        STORTIME    days of storage capacity required              /120/

* Design Parameter for Anaerobic Lagoon Construction
*---------------------------------------------------
        VSLOADRATE  volatile loading rate in Texas county         /5.3/
*                   (unit: lb VS/1000 cu.ft./day)
*                   (              USDA SCS (1992)  ASAE 1996 Standards)
*                   (Texas county       5.3              4.4)
*                   (Seminole county    5.7              4.7)
*                   (Source: USDA, SCS (1992), p.10-29;
*                             ASAE Standard 1996, p.592)
        SLRATIO     sludge accumulation ratio                      /0.0485/
*                   (unit: cu.ft./lb TS)
*                   (Source: USDA SCS(1992), p.10-30
*                            ASAE Standards 1996, p.593)
        SLPERIOD    sludge accumulation period-year                 /10/
*                   (Lagoons are commonly designed for
*                    a 15 to 20-year sludge accumulation period
*                    USDA SCS (1992), p.10-30)

* Costs of Building Construction and Waste Handling Equipments
*-------------------------------------------------------------
        DRILCOST    well drilling cost-Texas county                /14000/
        SCRENCOST   screen cost for well development-Texas county  /2310/
*       DRILCOST    well drilling cost-Seminole county             /4000/
*       SCRENCOST   screen cost for well development-Seminole county /660/
        CHOPPUMP    chopper pump price                             /13000/
        MOUNTPUMP   mounted pump                                   /10000/
        AGITATOR    agitator price                                 /7150/
        WAGPRICE    wagon price with price of tractor              /36666/
*                   (size - 3000 galon tractor; 1/3 price of tractor (125 HP)
        INJECTOR    injector                                       /2700/
        GUNPRICE    traveling gun price                            /21000/
*                   (984'-3.00ID)
```

```
        SLUGHOSE    sludge hose                                      /1168/
*                   (length of sludge hose: 600'*3.8")
        PVTPRICE    price of center pivot                            /35000/

* Unit Cost of Irrigating Apllication in the Storage Systems
*------------------------------------------------------------
       UCOSTHAUL   unit cost of hauling waste by tank wagon         /29.8/
       UCOSTIRTK   unit cost of irrigating tank                     /4.95/
       UCOSTIRPT   unit cost of irrigating pit                      /4.95/
       UCOSTIRLG   unit cost of irrigating lagoon                   /3.30/
       UCOSTELEC   unit cost of electricity                         /0.06/
       UCOSTLABR   unit cost of labor                               /6.00/
       UCOSTCVLG   unit cost of covering anaerobic lagoon           /4.10/
       UCOSTCVPT   unit cost of covering earthen pit                /1.02/
*                   (cost for plastic covering per market hog)
       UCOSTWATT   unit cost of water supply for traveling gun      /0.0008/
       UCOSTWATC   unit cost of water supply for center pivotn      /0.0005/ ;
*                   (dollar/cubic feet)

*************************
* Data Entry using Table
************************
* Table 1: Crop Nutrient Requirement (drawn from EPIC Simulation result)
*-------------------------------------------
TABLE CROPUSE(CROP,NUTRIENT,YIELD,TIME) crop nutrient requirements in the irrigation system
                            T01      T02      T03      T04      T05      T06
    CORN    .N    .LOW      0.00     0.00    16.80    16.80     0.00    33.60
    CORN    .N    .MED      0.00     0.00    22.40    22.40     0.00    44.80
    CORN    .N    .HIGH     0.00     0.00    28.00    28.00     0.00    56.00
    WHEAT   .N    .LOW      0.00    14.00    24.50    17.50     0.00     0.00
    WHEAT   .N    .MED      0.00    25.00    43.75    31.25     0.00     0.00
    WHEAT   .N    .HIGH     0.00    37.20    65.10    46.50     0.00     0.00
    CORN    .P    .LOW      0.00     0.00    11.21    11.21     0.00    22.43
    CORN    .P    .MED      0.00     0.00    14.95    14.95     0.00    29.90
    CORN    .P    .HIGH     0.00     0.00    18.69    18.69     0.00    37.38
    WHEAT   .P    .LOW      0.00     6.00    10.50     7.50     0.00     0.00
    WHEAT   .P    .MED      0.00    10.00    17.50    12.50     0.00     0.00
    WHEAT   .P    .HIGH     0.00    10.80    18.90    13.50     0.00     0.00

    +                       T07      T08      T09      T10      T11      T12
    CORN    .N    .LOW     84.00    16.80     0.00     0.00     0.00     0.00
    CORN    .N    .MED    112.00    22.40     0.00     0.00     0.00     0.00
    CORN    .N    .HIGH   140.00    28.00     0.00     0.00     0.00     0.00
    WHEAT   .N    .LOW      0.00     0.00    10.50     3.50     0.00     0.00
    WHEAT   .N    .MED      0.00     0.00    18.75     6.25     0.00     0.00
    WHEAT   .N    .HIGH     0.00     0.00    27.90     9.30     0.00     0.00
    CORN    .P    .LOW     56.07    11.21     0.00     0.00     0.00     0.00
    CORN    .P    .MED     74.76    14.95     0.00     0.00     0.00     0.00
    CORN    .P    .HIGH    93.45    18.69     0.00     0.00     0.00     0.00
    WHEAT   .P    .LOW      0.00     0.00     4.50     1.50     0.00     0.00
    WHEAT   .P    .MED      0.00     0.00     7.50     2.50     0.00     0.00
    WHEAT   .P    .HIGH     0.00     0.00     8.10     2.70     0.00     0.00;

TABLE CROPUSEH(CROP,NUTRIENT,YIELD,TIME) Crop nutrient requirement in the hauling system
                            T01      T02      T03      T04      T05      T06
    CORN    .N    .LOW      0.00     0.00    36.00   108.00     0.00    36.00
    CORN    .N    .MED      0.00     0.00    44.00   132.00     0.00    44.00
    CORN    .N    .HIGH     0.00     0.00    56.00   168.00     0.00    56.00
    WHEAT   .N    .LOW      0.00     0.00     0.00     0.00     0.00     0.00
    WHEAT   .N    .MED      0.00     0.00     0.00     0.00     0.00     0.00
    WHEAT   .N    .HIGH     0.00     0.00     0.00     0.00     0.00     0.00
    CORN    .P    .LOW      0.00     0.00    16.00    48.00     0.00    16.00
    CORN    .P    .MED      0.00     0.00    20.00    60.00     0.00    20.00
    CORN    .P    .HIGH     0.00     0.00    24.80    74.40     0.00    24.80
    WHEAT   .P    .LOW      0.00     0.00     0.00     0.00     0.00     0.00
    WHEAT   .P    .MED      0.00     0.00     0.00     0.00     0.00     0.00
    WHEAT   .P    .HIGH     0.00     0.00     0.00     0.00     0.00     0.00
```

```
 +                           T07     T08     T09     T10     T11     T12
 CORN    .N    .LOW         0.00    0.00    0.00    0.00    0.00    0.00
 CORN    .N    .MED         0.00    0.00    0.00    0.00    0.00    0.00
 CORN    .N    .HIGH        0.00    0.00    0.00    0.00    0.00    0.00
 WHEAT   .N    .LOW         0.00   14.00   42.00   14.00    0.00    0.00
 WHEAT   .N    .MED         0.00   25.00   75.00   25.00    0.00    0.00
 WHEAT   .N    .HIGH        0.00   37.20  111.60   37.20    0.00    0.00
 CORN    .P    .LOW         0.00    0.00    0.00    0.00    0.00    0.00
 CORN    .P    .MED         0.00    0.00    0.00    0.00    0.00    0.00
 CORN    .P    .HIGH        0.00    0.00    0.00    0.00    0.00    0.00
 WHEAT   .P    .LOW         0.00    6.00   18.00    6.00    0.00    0.00
 WHEAT   .P    .MED         0.00   10.00   30.00   10.00    0.00    0.00
 WHEAT   .P    .HIGH        0.00   10.80   32.40   10.80    0.00    0.00 ;

* Table 2: Characteristic of Swine Manure at Each Animal Types
*-------------------------------------------------------------
TABLE NUTRMAN(ANIMAL,NUTRIENT) pounds of nutrient content from daily manure
           N      P
NURS      0.02   0.012
FIN       0.07   0.050
GEST      0.07   0.050
SOW       0.10   0.055
BOAR      0.09   0.064   ;

*Source: 1992 ASAE Standard D384.1 (readapted data from MWPS. Livestock Waste
*         Facilities Handbook, MWPS-18, 1993, p.2.1.
*-----------------------------------------------------------------------

* Table 3: Solid Components of Swine Manure
*-----------------------------------------
TABLE MANSOLID(ANIMAL, SOLID) pounds of nutrient content from daily manure
           TS     VS
NURS      0.39   0.30
FIN       0.90   0.72
GEST      0.82   0.66
SOW       2.05   1.64
BOAR      1.04   0.84 ;

*Source: 1992 ASAE Standard D384.1 (readapted data from MWPS. Livestock Waste
*         Facilities Handbook, MWPS-18, 1993, p.2.1.
*-----------------------------------------------------------------------

* Table 4: Basic Information on the Storage Structures
*----------------------------------------------------
TABLE INFO(SYS, STORATT)
              SIZE       ACC         AMHAUL        N        P
TSYS1        83100      13033                    0.80     0.90
TSYS2       144500      17543                    0.80     0.90
TSYS3       222900      20747                    0.80     0.90
PIT                                              0.50     0.80
LAG1                                             0.30     0.40
LAG2                                             0.30     0.40    ;

* Source: Sutton, Alan L. et al., Swine Manure as a Plant Nutrient Resource,
*         in Pork Industry Handbook, Oklahoma Cooperative Extension Service,
*         PIH-25, February 1996. p.2.

* Table 6: Attributes of Transport Systems
*-----------------------------------------
TABLE TRANSINFO(APPSYS, ATTRIBUTES) attributes of manure transport systems
               VOL         ANNCOST          N        P
HSYS1          133          1869          0.97       1
HSYS2          267          2960          0.97       1
HSYS3          400          7283          0.97       1
IRRTANK                     4570          0.75       1
IRRPIT                      4570          0.75       1
IRRLAG                       371          0.75       1 ;
```

```
* Source: Sutton, Alan L. et al., Swine Manure as a Plant Nutrient Resource,
*         in Pork Industry Handbook, Oklahoma Cooperative Extension Service,
*         PIH-25, February 1996. p.2.
*

* Time Constraints for Storage System
TABLE TIMETANK(TANK,CROP,TIME)
                    T01     T02     T03     T04     T05     T06
TSYS1  .CORN         0       0       1       1       0       1
TSYS2  .CORN         0       0       1       1       0       1
TSYS3  .CORN         0       0       1       1       0       1
TSYS1  .WHEAT        0       1       1       1       0       0
TSYS2  .WHEAT        0       1       1       1       0       0
TSYS3  .WHEAT        0       1       1       1       0       0

+                   T07     T08     T09     T10     T11     T12
TSYS1  .CORN         1       1       0       0       0       0
TSYS2  .CORN         1       1       0       0       0       0
TSYS3  .CORN         1       1       0       0       0       0
TSYS1  .WHEAT        0       0       1       1       0       0
TSYS2  .WHEAT        0       0       1       1       0       0
TSYS3  .WHEAT        0       0       1       1       0       0 ;

TABLE TIMEPIT(CROP,TIME)
                    T01     T02     T03     T04     T05     T06
CORN                 0       0       1       1       0       1
WHEAT                0       1       1       1       0       0

+                   T07     T08     T09     T10     T11     T12
CORN                 1       1       0       0       0       0
WHEAT                0       0       1       1       0       0 ;

TABLE TIMELAG(LAGTYPE,CROP,TIME)
                    T01     T02     T03     T04     T05     T06
LAG1  .CORN          0       0       1       1       0       1
LAG1  .WHEAT         0       1       1       1       0       0
LAG2  .CORN          0       0       1       1       0       1
LAG2  .WHEAT         0       1       1       1       0       0

+                   T07     T08     T09     T10     T11     T12
LAG1  .CORN          1       1       0       0       0       0
LAG1  .WHEAT         0       0       1       1       0       0
LAG2  .CORN          1       1       0       0       0       0
LAG2  .WHEAT         0       0       1       1       0       0 ;

* Table 7: Initial Cropland Assignment
TABLE ACRENO(CROP,YIELD)
           LOW     MED     HIGH
CORN                        256
WHEAT                          ;

* Table 8: Net Return from Crop Prodcution Activity
*          (excluding fertilizing cost)
*------------------------------------------------
TABLE NETRCROP(CROP,YIELD) net return of crop production
                  LOW      MED      HIGH
*               (------ dollar/acre----)
CORN             78.50   129.80    161.22
WHEAT            65.33   112.59    149.25 ;

* Assuming the following expected yield of crop production
*                  LOW      MED      HIGH
*                (------pounds/acre-----)
* CORN             127      148      161
* WHEAT             40       60       80 ;

* Table 9: Environmental Regulation Considered
*-----------------------------------------------
```

```
TABLE ANIMALCAP(SYS,ANIMAL) animal capacity per acre
              NURS      FIN     GEST      SOW      BOAR
*            (--------------head/acre------------------)
TSYS1          80        17      25        13       25
TSYS2          80        17      25        13       25
TSYS3          80        17      25        13       25
LAG1          320        65      90        40       90
LAG2          320        65      90        40       90
PIT            80        17      25        13       25;

* Note: The regulatory framework is drawn from the environmental regulation
*       Indiana State (1996). This regulation will be used for potential
*       constraints for Oklahoma swine operation.
*-------------------------------------------------------------------

*********************
* Parameters
*********************
PARAMETER ANIMALNO(ANIMAL) maximum capacity of animal in each categories
        / NURS     0
          FIN    1000
          GEST     0
          SOW      0
          BOAR     0 /;

PARAMETER MANGENR(ANIMAL)  manure produced pound per day
        / NURS   2.3
          FIN    9.8
          GEST   9.0
          SOW   22.5
          BOAR  11.5 /;

PARAMETER WEIGHT(ANIMAL) weight of animal in pounds
        / NURS     35.0
          FIN     190.0
          GEST    275.0
          SOW     375.0
          BOAR    350.0 /;

* The data on manure generation and animal weight are drawn from
*  MWPS, Livestock Waste Facilities Handbook, 1993, p.2.1.
*-------------------------------------------------------------------------

PARAMETER SPACEREQ(ANIMAL) space requirement for building per animal square ft
        /NURS   3.5
         FIN    8
         GEST   15
         SOW    27
         BOAR   40  /;

* Source: MWPS, Swine Housing and Equipment Handbook, MWPS-8, 1983.

PARAMETER NETRSWINE(ANIMAL) net return for swine production
*        dollar/head
        /NURS   0
         FIN    16.46
         GEST   0
         SOW    0
         BOAR   0  /;

PARAMETER PRICENPK(NUTRIENT) price per pound
*         dollar/pound
       / N  0.25
         P  0.11  /;

* The data is drawn from OSU Enterprise Budget (1995).
*---------------------------------------------------------------------
```

```
PARAMETER BEGAMINVTK(TIME) begining inventroy of tank system
     / T01  0
       T02  0
       T03  0
       T04  0
       T05  0
       T06  0
       T07  0
       T08  0
       T09  0
       T10  0
       T11  0
       T12  0 /;

PARAMETER AVALABOR(TIME) available amount of labor in time period t
     / T01  160
       T02  160
       T03  160
       T04  160
       T05  160
       T06  160
       T07  160
       T08  160
       T09  160
       T10  160
       T11  160
       T12  160 /;


PARAMETER CUSTCOST(YIELD) custom hauling cost for excess nutrient disposal
*      (unit: dollar/acre)
      /LOW    117
       MED    117
       HIGH   117 /;

* Environmental Regulation for Waste Application Rate
PARAMETER MAXAPPRATE(NUTRIENT) maximum level of waste application rate
    / N  0.00
      P  0.00 /;

*****************************************************
* Parameters I - Calculating Manure Generation
****************************************************

PARAMETER TSWINENO `total number of hog';
    TSWINENO = SUM(ANIMAL, ANIMALNO(ANIMAL));

PARAMETER MMANGENR(ANIMAL,TIME) `monthly manure generation at time t-pound';
    MMANGENR(ANIMAL,TIME) = ANIMALNO(ANIMAL)*MANGENR(ANIMAL)*CARD(TIME)*30/12;

PARAMETER TMANGENR(ANIMAL) `total amount of manure per animal yearly-pound';
     TMANGENR(ANIMAL) =  SUM(TIME, MMANGENR(ANIMAL,TIME));

*****************************************************************
* Parameter II - Calculating Nutrient Content and Requirement
*****************************************************************
PARAMETER TNUTR(NUTRIENT,TIME) `monthly nutrient generation cu ft at time t';
      TNUTR(NUTRIENT,TIME) = SUM(ANIMAL, ANIMALNO(ANIMAL)*
                             NUTRMAN(ANIMAL,NUTRIENT)*
                             CARD(TIME)*30/12);

PARAMETER MNUTREQ(NUTRIENT,TIME) `monthly nutrient requirement for irrigation';
      MNUTREQ(NUTRIENT,TIME) = SUM((CROP,YIELD), ACRENO(CROP,YIELD)*
                     CROPUSE(CROP,NUTRIENT,YIELD,TIME));

PARAMETER TNUTREQ(NUTRIENT) `total nutrient requirement for irrigation system';
      TNUTREQ(NUTRIENT) = SUM(TIME, MNUTREQ(NUTRIENT,TIME));
```

```
PARAMETER MNUTREQH(NUTRIENT,TIME) `monthly nutrient requirement for hauling';
      MNUTREQH(NUTRIENT,TIME) = SUM((CROP,YIELD), ACRENO(CROP,YIELD)*
                      CROPUSEH(CROP,NUTRIENT,YIELD,TIME));

PARAMETER TNUTREQH(NUTRIENT) `total nutrient requirement for hauling system';
      TNUTREQH(NUTRIENT) = SUM(TIME, MNUTREQH(NUTRIENT,TIME));

PARAMETER TNUTGENR(NUTRIENT) `total available nutrent generated';
       TNUTGENR(NUTRIENT) = SUM(TIME, TNUTR(NUTRIENT,TIME));

***************************************************************
* Parameter III - Calculating Capacities of Storage Systems
***************************************************************
PARAMETER MMANVOL(TIME) `monthly volume of manure generated at time t';
      MMANVOL(TIME) = SUM(ANIMAL, MMANGENR(ANIMAL,TIME)*0.0160);

* Unit conversion factor from pound to cu.ft.: 0.0160

PARAMETER MANVOL `volume of swine manure generated for storage cubic ft';
      MANVOL = SUM(TIME, MMANVOL(TIME));

PARAMETER WWATERVOL(TIME) `volume of waste water-cubic ft';
      WWATERVOL(TIME) = MMANVOL(TIME)* 18.0;
* The volume of waste water in a pit recharge system was calculated from the relationship
* between pit size and cleaning frequency
* (once a 3 day frequency - 2.70 cu.ft./day additional water volume required)
* (equivalent to 18 times of manure volume generated)

PARAMETER MWASTEVOL(TIME) `volume of manure and waste water -cubic feet';
     MWASTEVOL(TIME) = (MMANVOL(TIME)+WWATERVOL(TIME));

* Size of Tank System Required
*------------------------------
PARAMETER TANKSIZE(SYS,STORATT) `size of tank required-cubic feet';
      TANKSIZE('TSYS3','SIZE') = 2.85*TSWINENO*STORTIME;

* Size of Outside Storage Pit System Required
*---------------------------------------------
PARAMETER SAFEVOLPT `safety volume of pit required-cubic ft';
      SAFEVOLPT = 17571.8 + 105.98*TSWINENO;

PARAMETER PITSIZE(SYS,STORATT) `size of manure pit required-cubic ft';
      PITSIZE('PIT','SIZE') = (2.85*TSWINENO*STORTIME)+SAFEVOLPT;

* Size of Laggon System Required
*------------------------------
PARAMETER TSVOL `amount of total solid in swine manure-lbs';
      TSVOL = SUM(ANIMAL, ANIMALNO(ANIMAL) * MANSOLID(ANIMAL,'TS'));

PARAMETER VSVOL `volume of volatile solid in swine manure-lbs';
      VSVOL = SUM(ANIMAL, ANIMALNO(ANIMAL) * MANSOLID(ANIMAL,'VS'))

PARAMETER LAGMINVOL `minimum treatment volume of anaerobic lagoon-cu ft';
      LAGMINVOL = (VSVOL * 1000)/VSLOADRATE;

PARAMETER LAGFWVOL(LAGTYPE) `additional flushing water volume-cu ft';
      LAGFWVOL(LAGTYPE) = LAGMINVOL * 0.3;

PARAMETER LAGSLVOL  `sludge volume requirement-cubic ft';
      LAGSLVOL = 365 * SLPERIOD * TSVOL * SLRATIO;

PARAMETER LAGMANVOL  `manure treatment volume requirement-cubic ft';
      LAGMANVOL = MANVOL *(STORTIME/360);

PARAMETER LAGSFVOL `lagoon adjustment volume for safety factor';
     LAGSFVOL = 5692.398+20.51644*TSWINENO;

PARAMETER LAGSIZE(SYS,ATTRIBUTES) `lagoon volume requirement -cubic feet';
```

```
     LAGSIZE(LAGTYPE,'SIZE') =  LAGMANVOL + LAGFWVOL(LAGTYPE) +
                                LAGMINVOL + LAGSLVOL + LAGSFVOL;

* The size of the lagoon could be calculated by several methods.
* This method is based on the total solid, volatile soild,
* sludge build-up and runoff volumes (USDA, NRCS, 1992).

*************************************************************************************
* PARAMETERS IV -Calcualating Amount of Feasible Hauling Waste
*************************************************************************************

PARAMETER MHAULVOLTK(SYS,ATTRIBUTES,TIME) `hauling amount from tank at time t`;
       MHAULVOLTK(TANK,'AMHAUL',TIME) = MWASTEVOL(TIME)*(1-STORTIME/360)*
                                        SUM(CROP,TIMETANK(TANK,'CORN',TIME));

PARAMETER HAULVOLTK(SYS,ATTRIBUTES) `total manure haul per year from tank`;
       HAULVOLTK(TANK,'AMHAUL') = SUM(TIME, MHAULVOLTK(TANK,'AMHAUL',TIME));

PARAMETER MHAULVOLPT(SYS,ATTRIBUTES,TIME) `hauling amount from pit at time t';
       MHAULVOLPT('PIT','AMHAUL',TIME) = MWASTEVOL(TIME)*(1-STORTIME/360)*
                                         SUM(CROP,TIMEPIT('CORN',TIME));

PARAMETER HAULVOLPT(SYS,ATTRIBUTES) `total manure haul per year from pit';
       HAULVOLPT('PIT','AMHAUL') = SUM(TIME, MHAULVOLPT('PIT','AMHAUL',TIME));


PARAMETER MHAULVOLLG(LAGTYPE,ATTRIBUTES,TIME) `hauling amount from lagoon;
       MHAULVOLLG(LAGTYPE,'AMHAUL',TIME) = LAGSIZE('LAG1','SIZE')*0.0625*
                             SUM(CROP,TIMELAG(LAGTYPE,'CORN',TIME));

PARAMETER HAULVOLLG(SYS,ATTRIBUTES) `hauling amount from lagoon at time t';
       HAULVOLLG(LAGTYPE,'AMHAUL') = LAGSIZE('LAG1','SIZE')*0.15;

PARAMETER BEGINVTK(TANK,TIME) `begining inventory of tank system in time t;
       BEGINVTK(TANK,TIME) =  BEGAMINVTK(TIME)+MMANVOL(TIME--1)-
                              MHAULVOLTK(TANK,'AMHAUL',TIME--1);

PARAMETER BEGINVPT(TIME) `begining inventory of pit system in time t;
       BEGINVPT(TIME) = MMANVOL(TIME--1)- MHAULVOLPT('PIT','AMHAUL',TIME--1);

*************************************************************************************
* PARAMETERS V - Calculating Annual Capital Cost of Storage Structures
*************************************************************************************

PARAMETER TANKCCOST `construction cost of tank system';
      TANKCCOST = ( 1.05$(TANKSIZE('TSYS3','SIZE') LE 100000)+
                    1.01$(TANKSIZE('TSYS3','SIZE') GT 100000 AND
                          TANKSIZE('TSYS3','SIZE') LE 200000)+
                    0.98$(TANKSIZE('TSYS3','SIZE') GT 200000 AND
                          TANKSIZE('TSYS3','SIZE') LE 300000)+
                    0.94$(TANKSIZE('TSYS3','SIZE') GT 300000 AND
                          TANKSIZE('TSYS3','SIZE') LE 400000)+
                    0.90$(TANKSIZE('TSYS3','SIZE') GT 400000))*
                          TANKSIZE('TSYS3','SIZE');

PARAMETER TANKECOST `equipment cost of tank system';
      TANKECOST = AGITATOR + MOUNTPUMP;

PARAMETER TANKCICOST(SYS,STORATT) `capital investment cost of tank system';
      TANKCICOST(TANK,'CIC') = TANKECOST + TANKCCOST;

PARAMETER ANTNKCOST(SYS,STORATT) `annual cost of tank system';
      ANTNKCOST(TANK,'ACC') = (TANKECOST*0.185)+(TANKCCOST*0.092);

PARAMETER PITCCOST `construction cost for outside pit;
      PITCCOST =  (0.10$(PITSIZE('PIT','SIZE') LE 500000)+
                   0.09$(PITSIZE('PIT','SIZE') GT 5000000 AND
                         PITSIZE('PIT','SIZE') LE 1000000)+
```

```
                  0.08$(PITSIZE('PIT','SIZE') GT 1000000 AND
                       PITSIZE('PIT','SIZE')  LE 1500000)+
                  0.07$(PITSIZE('PIT','SIZE') GT 1500000 AND
                      PITSIZE('PIT','SIZE')   LE 2000000)+
                  0.06$(PITSIZE('PIT','SIZE') GT 2000000))*
                  PITSIZE('PIT','SIZE');

PARAMETER PITFCOST `fencing cost of pit';
       PITFCOST = 2.5*(558.938+0.142*TSWINENO);

PARAMETER PITECOST `equipment cost of pit system';
       PITECOST = AGITATOR+PITFCOST;

PARAMETER PITCICOST(SYS,STORATT) `capital investment cost of pit system';
       PITCICOST('PIT','CIC') = PITCCOST + PITECOST +PITFCOST;

PARAMETER ANPITCOST(SYS,STORATT) `annual cost of pit system';
       ANPITCOST('PIT','ACC') = (PITECOST*0.185)+(PITCCOST*0.092)+
                                (PITFCOST*0.112);

PARAMETER LAGCCOST(SYS) `construction costs of an anaerobic lagoon';
    LAGCCOST(LAGTYPE) = (0.10$(LAGSIZE(LAGTYPE,'SIZE') LE 500000)+
                        0.09$(LAGSIZE(LAGTYPE,'SIZE') GT 500000 AND
                              LAGSIZE(LAGTYPE,'SIZE') LE 1000000)+
                        0.08$(LAGSIZE(LAGTYPE,'SIZE') GT 1000000 AND
                              LAGSIZE(LAGTYPE,'SIZE') LE 1500000)+
                        0.07$(LAGSIZE(LAGTYPE,'SIZE') GT 1500000 AND
                              LAGSIZE(LAGTYPE,'SIZE') LE 2000000)+
                        0.06$(LAGSIZE(LAGTYPE,'SIZE') GT 2000000)) *
                        LAGSIZE(LAGTYPE,'SIZE');

PARAMETER LAGECOST `equipment cost of lagoon';
   LAGECOST = CHOPPUMP;

PARAMETER LAGCICOST(SYS,STORATT) `capital investment cost of lagoon system';
   LAGCICOST(LAGTYPE,'CIC') = LAGECOST+LAGCCOST(LAGTYPE);

PARAMETER ANLAGCOST(SYS,STORATT) `annual cost of lagoon system';
   ANLAGCOST(LAGTYPE,'ACC') = (LAGECOST*0.185) + (LAGCCOST(LAGTYPE)*0.092);

PARAMETER ATTRI(SYS,ATTRIBUTES) `parameters for table info';
       ATTRI(SYS,STORATT) = INFO(SYS,STORATT)          +
                            TANKSIZE(SYS,STORATT)      +
                            LAGSIZE(SYS,STORATT)       +
                            PITSIZE(SYS,STORATT)       +
                            TANKCICOST(SYS,STORATT)    +
                            PITCICOST(SYS,STORATT)     +
                            LAGCICOST(SYS,STORATT)     +
                            ANLAGCOST(SYS,STORATT)     +
                            ANTNKCOST(SYS,STORATT)     +
                            ANPITCOST(SYS,STORATT)     +
                            HAULVOLTK(SYS,STORATT)     +
                            HAULVOLPT(SYS,STORATT)     +
                            HAULVOLLG(SYS,STORATT) ;

***********************************************************************
* Parameters VI - Calculating Labor Requirement in Handling Waste
***********************************************************************

* Hauling System
*---------------
PARAMETER MHAULHTK(SYS,APPSYS,TIME) `monthly hours required to haul tank';
        MHAULHTK(TANK,HAULTANK,TIME) = (MHAULVOLTK(TANK,'AMHAUL',TIME))/
                                       (TRANSINFO(HAULTANK,'VOL')*3);
PARAMETER MHAULHPIT(SYS,APPSYS,TIME) `monthly hours required to haul pit';
        MHAULHPIT(PIT,HAULPIT,TIME) = (MHAULVOLPT(PIT,'AMHAUL',TIME))/
                                      (TRANSINFO(HAULPIT,'VOL')*3);
PARAMETER MHAULHLAG(SYS,APPSYS,TIME) `monthly hours required to haul lagoon';
```

```
        MHAULHLAG(LAGTYPE,HAULLAG,TIME) = (MHAULVOLLG(LAGTYPE,'AMHAUL',TIME))/
                                          (TRANSINFO(HAULLAG,'VOL')*3);
PARAMETER HOURTKLAG(SYS,APPSYS) `hours required to haul tank or lagoon';
        HOURTKLAG(TANKLAG,HAULTKLAG) = ATTRI(TANKLAG,'AMHAUL')/
                                    (TRANSINFO(HAULTKLAG,'VOL')*3);
PARAMETER HOURPIT(SYS,APPSYS) `hours required to haul pit';
        HOURPIT('PIT',HAULPIT) = ATTRI('PIT','AMHAUL')/
                                    (TRANSINFO(HAULPIT,'VOL')*3);

PARAMETER MHAULHOUR(SYS,APPSYS,TIME) `monthly hours required to haul storage';
        MHAULHOUR(SYS,APPSYS,TIME) = MHAULHTK(SYS,APPSYS,TIME) +
                                     MHAULHPIT(SYS,APPSYS,TIME)+
                                     MHAULHLAG(SYS,APPSYS,TIME);
PARAMETER HAULHOUR(SYS,APPSYS) `hours required to haul storage waste';
        HAULHOUR(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*
                               (HOURTKLAG(SYS,APPSYS) +
                                HOURPIT(SYS,APPSYS));

* Note: The parameter for loading availability is based on the assumption
*       that the swine operator is able to haul 3 loads an hour.
*       (This information is drawn from USDA SCS (1992) and Lazarus (1993).
*---------------------------------------------------------------------------

* Pumping Systems
*-----------------

PARAMETER HOURIRTK(SYS,APPSYS) `hours needed to pump when tanks are irrigated';
      HOURIRTK(TANK,'IRRTANK') = ATTRI(TANK,'AMHAUL')/2400;

PARAMETER HOURIRPIT(SYS,APPSYS) `hours needed to pump when pit is irrigated';
      HOURIRPIT('PIT','IRRPIT') = ATTRI('PIT','AMHAUL')/2400;

PARAMETER HOURIRLAG(SYS,APPSYS) `hours needed to pump when lagoon isirrigated';
      HOURIRLAG(LAGTYPE,'IRRLAG') = ATTRI(LAGTYPE,'AMHAUL')/5600;

* The pumping capacity (300 gpm) in a traveling gun system is assumed,
* i.e., 2400 cubic feet per hour and the pumping capacity in a center
* pivot system is assumed to be 700 gpm.
* (1 gallon = 0.1337 cu.ft)

PARAMETER PUMPHOUR(SYS,APPSYS) `hours required to pump storage waste';
      PUMPHOUR(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*
                             (HOURIRTK(SYS,APPSYS) +
                              HOURIRPIT(SYS,APPSYS)+
                              HOURIRLAG(SYS,APPSYS));

* Labor Requiement for Pumping System
*--------------------------------------
PARAMETER LABIRRTK(SYS,APPSYS) `labor required to irrigate tank';
      LABIRRTK(TANK,'IRRTANK') = ATTRI(TANK,'AMHAUL')/51857;

PARAMETER LABIRRPIT(SYS,APPSYS) `labor required to irrigate pit';
      LABIRRPIT('PIT','IRRPIT') = ATTRI('PIT','AMHAUL')/51857;

PARAMETER LABIRRLAG(SYS,APPSYS) `labor required to irrigate lagoons';
      LABIRRLAG(LAGTYPE,'IRRLAG') = ATTRI(LAGTYPE,'AMHAUL')/363000;

*Note: Labor requirement for sprinkler irrigation system
*      Traveling gun -  0.07 hrs/acre-inch -> 51,857 cu.ft./hour
*      Center pivot  -  0.01 hrs/acre-inch -> 363,000 cu.ft./hour
*      Note: 1 acre-inch = 3,630 cu.ft.
*      (Source:Solomon, K.H. "Irrigation Notes", Center for Irrigation
*       Technology, California State University, CATI Pub. No. 880105,
*       Jan. 1988, p.6.)

PARAMETER LABIRR(SYS,APPSYS) `labor required when irrigating';
      LABIRR(SYS,APPSYS) =(1$COMBSYS(SYS,APPSYS))*
                         (LABIRRTK(SYS,APPSYS) +
```

```
                         LABIRRPIT(SYS,APPSYS)+
                         LABIRRLAG(SYS,APPSYS));

****************************************************************************
* PARAMETER VII - Caculating Annual Operating Cost of Storage System
****************************************************************************

* Hauling Costs
******************

PARAMETER HAULCOST(SYS,APPSYS) `hauling costs of storage systems';
     HAULCOST(SYS,APPSYS) = HAULHOUR(SYS,APPSYS)*UCOSTHAUL;

PARAMETER HCOSTLABTK(SYS,APPSYS) `labor cost to haul tank system';
     HCOSTLABTK(TANK, HAULTANK) = HOURTKLAG(TANK,HAULTANK)*UCOSTLABR;

PARAMETER HCOSTLABPT(SYS,APPSYS) `cost to haul pit with wagon';
     HCOSTLABPT('PIT',HAULPIT) = HOURPIT('PIT',HAULPIT)*UCOSTLABR;

PARAMETER HCOSTLABLG(SYS,APPSYS) `cost to haul lagoon system';
     HCOSTLABLG(LAGTYPE, HAULLAG) = HOURTKLAG(LAGTYPE,HAULLAG)*UCOSTLABR;

PARAMETER HCOSTLABR(SYS,APPSYS) `labor costs of hauling systems';
     HCOSTLABR(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*
                         (HCOSTLABTK(SYS,APPSYS)  +
                          HCOSTLABPT(SYS,APPSYS)   +
                          HCOSTLABLG(SYS,APPSYS))  ;

* Irrigating Costs
******************************************
* Energy Cost
*----------------------------------
PARAMETER ACOSTTANK(SYS, APPSYS) `cost to irrigate tank using traveling gun';
     ACOSTTANK(TANK,'IRRTANK') = HOURIRTK(TANK,'IRRTANK')*UCOSTIRTK;

PARAMETER ACOSTPIT(SYS, APPSYS) `cost to irrigate pit using travel gun';
     ACOSTPIT('PIT','IRRPIT') = HOURIRPIT('PIT','IRRPIT')*UCOSTIRPT;

PARAMETER ICOSTLAG(SYS,APPSYS) `cost to irrigate lagoon using center pivot';
     ICOSTLAG(LAGTYPE,'IRRLAG') = (HOURIRLAG(LAGTYPE,'IRRLAG')*UCOSTIRLG);

PARAMETER ICOSTPUMP(SYS,APPSYS) `cost of agitating and chopper pumping';
     ICOSTPUMP(SYS, APPSYS) = (1$COMBSYS(SYS,APPSYS))*
                           (ACOSTTANK(SYS,APPSYS)  +
                            ACOSTPIT(SYS,APPSYS)   +
                            ICOSTLAG(SYS,APPSYS))   ;

* Labor Cost to Irrigation System
*-----------------------------------
PARAMETER LCOSTIRTK(SYS,APPSYS) `labor cost to irrigate tank';
     LCOSTIRTK(TANK,'IRRTANK') = LABIRR(TANK,'IRRTANK')*UCOSTLABR;

PARAMETER LCOSTIRPIT(SYS,APPSYS) `labor cost to irrigate pit';
     LCOSTIRPIT('PIT','IRRPIT') = LABIRR('PIT','IRRPIT')*UCOSTLABR;

PARAMETER LCOSTIRLAG(SYS,APPSYS) `labor cost to irrigate lagoon';
     LCOSTIRLAG(LAGTYPE,'IRRLAG') = LABIRR(LAGTYPE,'IRRLAG')*UCOSTLABR;

PARAMETER LCOSTAPP(SYS,APPSYS) `labor cost for irrigation system';
     LCOSTAPP(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*
                         (LCOSTIRTK(SYS,APPSYS)    +
                          LCOSTIRPIT(SYS,APPSYS)   +
                          LCOSTIRLAG(SYS,APPSYS))  ;

* Cost of Electric Use (If energy use is based on an electic system)
*------------------------------------------------------------------------
PARAMETER ECOSTPUMTK(SYS,APPSYS) `cost of electric use in tank-traveling gun';
      ECOSTPUMTK(TANK,'IRRTANK') = (ATTRI(TANK,'AMHAUL')/84)*UCOSTELEC;
```

```
PARAMETER ECOSTPUMPT(SYS,APPSYS) `cost of elecectic use in pit-traveling gun';
      ECOSTPUMPT('PIT','IRRPIT') = (ATTRI('PIT','AMHAUL')/84)*UCOSTELEC;

PARAMETER ECOSTPUMLG(SYS,APPSYS) `cost of electric use in lagoon-center pivot';
      ECOSTPUMLG(LAGTYPE,'IRRLAG') = (ATTRI(LAGTYPE,'AMHAUL')/226)*UCOSTELEC;

* Source: Energy use for sprinkler irrigation system
*       Traveling gun -  43 kwh/acre-inch    -> 84  cu.ft./kwh
*       Center pivot  -  16 kwh/acre-inch    -> 226 cu.ft./kwh
*       (Source:Solomon, K.H. "Irrigation Notes", Center for Irrigation
*        Technology, California State University, CATI Pub. No. 880105,
*        Jan. 1988, p.6.)

PARAMETER ECOSTPUMP(SYS,APPSYS) `cost of electricity for application system';
     ECOSTPUMP(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*
                            (ECOSTPUMTK(SYS,APPSYS)  +
                             ECOSTPUMPT(SYS,APPSYS)  +
                             ECOSTPUMLG(SYS,APPSYS))  ;

PARAMETER IRRCOST(SYS,APPSYS) `cost of operating irrigation systems';
      IRRCOST(SYS,APPSYS) =  ICOSTPUMP(SYS,APPSYS) + LCOSTAPP(SYS,APPSYS);

* Maintenance Costs
*--------------------------------------------
PARAMETER MCOSTTKHL(SYS,APPSYS) `maintenance cost of tank system with hauling';
     MCOSTTKHL(TANK,HAULTANK) = (TANKCCOST*0.04)+(TANKECOST*0.04)+
                                (WAGPRICE*0.05) + (INJECTOR*0.05);

PARAMETER MCOSTTKIR(SYS,APPSYS) `maintenance cost of tank system with pumping';
     MCOSTTKIR(TANK,'IRRTANK') = (TANKCCOST*0.04)+(TANKECOST*0.04)+
                                 (GUNPRICE*0.04);

PARAMETER MCOSTPTHL(SYS,APPSYS) `maintenance cost of pit system with hauling';
     MCOSTPTHL('PIT',HAULPIT) = (PITCCOST*0.02) + (PITECOST*0.04)+
                                (WAGPRICE*0.05) + (INJECTOR*0.05) +
                                (PITFCOST*0.02) ;

PARAMETER MCOSTPTIR(SYS,APPSYS) `maintenance cost of pit system with pumping';
     MCOSTPTIR('PIT','IRRPIT') = (PITCCOST*0.02)+(PITECOST*0.04)+
                                  (GUNPRICE*0.04) +(PITFCOST*0.02);

PARAMETER MCOSTLGHL(SYS,APPSYS) `maintenance cost of lagoons with hauling';
     MCOSTLGHL(LAGTYPE, HAULLAG) = (LAGCCOST(LAGTYPE)*0.02)+(LAGECOST*0.03) +
                                (WAGPRICE*0.05)+(INJECTOR*0.05);

PARAMETER MCOSTLGIR(SYS,APPSYS) `maintenance cost of lagoons with pumping';
     MCOSTLGIR(LAGTYPE, 'IRRLAG') = (LAGCCOST(LAGTYPE)*0.02)+
                                (LAGECOST*0.03) + (PVTPRICE*0.02);

PARAMETER MCOSTSYS(SYS,APPSYS) `mainten cost of stor and application system';
     MCOSTSYS(SYS,APPSYS) =  (1$COMBSYS(SYS,APPSYS))*
                            (MCOSTTKHL(SYS,APPSYS) +
                             MCOSTTKIR(SYS,APPSYS) +
                             MCOSTPTHL(SYS,APPSYS) +
                             MCOSTPTIR(SYS,APPSYS) +
                             MCOSTLGHL(SYS,APPSYS) +
                             MCOSTLGIR(SYS,APPSYS)) ;

* Water Supply Cost
*-------------------
PARAMETER WCOSTTANK(SYS,APPSYS) `cost of water supply in tank system';
    WCOSTTANK('TSYS3',APPSYS) = 2.7*360*TSWINENO*UCOSTWATT;

PARAMETER WCOSTPIT(SYS,APPSYS) `cost of water supply in pit system';
    WCOSTPIT('PIT',APPSYS)    = 2.7*360*TSWINENO*UCOSTWATT;

PARAMETER WCOSTLAG(SYS,APPSYS) `cost of water supply in lagoon system';
    WCOSTLAG(LAGTYPE, APPSYS) = 2.7*360*TSWINENO*UCOSTWATC;
```

```
PARAMETER WATERCOST(SYS,APPSYS) `cost of water supply';
    WATERCOST(SYS,APPSYS)=   (1$COMBSYS(SYS,APPSYS)) *
                             (WCOSTTANK(SYS,APPSYS) +
                              WCOSTPIT(SYS,APPSYS)  +
                              WCOSTLAG(SYS,APPSYS))  ;
* License Fee
*-------------

PARAMETER LICENFEE `license isurance and renewal fee';
     LICENFEE =  15.00$(TSWINENO LE 625) +
                 37.50$(TSWINENO GT 625  AND TSWINENO LE 1250 )+
                 75.00$(TSWINENO GT 1250 AND TSWINENO LE 7500 )+
                150.00$(TSWINENO GT 7500 AND TSWINENO LE 25000)+
                225.00$(TSWINENO GT 25000);

* The fees for swine feeding operations license and annual was drawn from
* OCAFOA of 1997 (Section 14 - C)

*******************************************************************************
* PARAMETERS VIII - CALCULATING ENGINEERING COSTS OF STORAGE-APPLICATION SYSTEMS
*******************************************************************************

* Operating Cost
*****************

PARAMETER ANOPCOST(SYS,APPSYS) `annual operating costs for system management';
      ANOPCOST(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*
                             (HAULCOST(SYS,APPSYS) +
                              IRRCOST(SYS,APPSYS)  +
                              MCOSTSYS(SYS,APPSYS)  +
                              WATERCOST(SYS,APPSYS) +
                              LICENFEE);

* Capital Costs
*-----------------

PARAMETER ICAPCOST(SYS,APPSYS) `initial investment cost of storage system';
      ICAPCOST(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*ATTRI(SYS,'CIC');

PARAMETER ACAPSCOST(SYS,APPSYS) `annual capital costs of storage system';
      ACAPSCOST(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*ATTRI(SYS,'ACC');

PARAMETER ACAPACOST(SYS,APPSYS) `annual capital costs of application system';
      ACAPACOST(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*
                              TRANSINFO(APPSYS,'ANNCOST');

PARAMETER ANCAPCOST(SYS,APPSYS) `annual capital costs of w-management system';
      ANCAPCOST(SYS,APPSYS) = ACAPSCOST(SYS,APPSYS) + ACAPACOST(SYS,APPSYS);

PARAMETER TOTALCOST(SYS,APPSYS) `Total annual cost of w-management system ';
      TOTALCOST(SYS,APPSYS) = (1$COMBSYS(SYS,APPSYS))*
                              (ANOPCOST(SYS,APPSYS) +ANCAPCOST(SYS,APPSYS));

**********************************************************************
* PARAMETERS IX - Specifying Effective System: Storage-Application
************************************************************************

PARAMETER EXTANK(SYS) `excess capacity for manure tanks';
       EXTANK(SYS) = 4*INFO(SYS,'SIZE') - TANKSIZE('TSYS3','SIZE');

* Assuming that the same size of three tank systems is allowed.
PARAMETER EFSTOR(SYS) `systems which are allowed or not';
      EFSTOR(SYS) = 1$(EXTANK(SYS) GE 0 OR
                    LAGSIZE(SYS,'SIZE') GT 0 OR
                    PITSIZE(SYS,'SIZE') GT 0);

PARAMETER EFFSYS(SYS,APPSYS) `allowed storage and hauling sysems';
       EFFSYS(SYS,APPSYS) = 1$(EXTANK(SYS) AND TOTALCOST(SYS,APPSYS));
```

```
*****************************************************************************
* Parameter XI - Environmental Regulation Considered
*****************************************************************************

PARAMETER REQACRE(SYS,ANIMAL) `total acreage required to meet animal unit';
       REQACRE(SYS,ANIMAL) = ANIMALNO(ANIMAL)/ANIMALCAP(SYS,ANIMAL);

***************************************************
* Display for the Values of Major Parameters
***************************************************

DISPLAY ANIMALNO,  TNUTGENR, TNUTREQ, TANKSIZE, PITSIZE, LAGSIZE;
DISPLAY ATTRI, MHAULVOLLG;
DISPLAY TANKCCOST, TANKECOST, ANTNKCOST,
        PITCCOST, PITECOST, PITFCOST, ANPITCOST,
        LAGCCOST, LAGECOST, ANLAGCOST;
DISPLAY MHAULHOUR, HAULHOUR, PUMPHOUR;
DISPLAY LABIRR, HCOSTLABR, HAULCOST, LCOSTAPP, IRRCOST, ECOSTPUMP,
        MCOSTSYS, WATERCOST, LICENFEE;
DISPLAY ANOPCOST, ACAPSCOST, ACAPACOST, ANCAPCOST, TOTALCOST;

****************************************
* VARIABLES
****************************************

VARIABLES  decision variable to be determoned
         TYPE(SYS,APPSYS)         optimal waste management system
         AVMANNUTR(NUTRIENT)      available manure nutrient
         ALAND(CROP,YIELD)        additional land and crop (acres)
         AMFERT(NUTRIENT)         amount og fertilizer required
         FERTCOST                 fertilizer cost
         EXCNUTR(NUTRIENT)        excess nutrient (pounds)
         TAMEXNUTR(NUTRIENT)      total amount of excess nutrient
         Z                        net revenue (dollar);

POSITIVE VARIABLE   AMFERT, FERTCOST, EXCNUTR, ALAND;
BINARY VARIABLE     TYPE;

****************************************
* EQUATIONS
****************************************

EQUATIONS
     CONSTEFSYS                 constraint for effective system
     TOTAVNUTR(NUTRIENT)        total available nutrient
     CONSTAFER(NUTRIENT)        constraint for crop nutrient requirement 1
     ACFERTVAL                  accounting fertilizer value
     CONSTNEXC(NUTRIENT)        constraint for crop nutrient requirement 2
     ADDLAND(NUTRIENT)          additional land needed
     BALEQTANK(TANK,TIME)       balance equation for tank system
     BALEQPIT(TIME)             balance equation for pit system
     CONSTLABOR(TIME)           labor constraint
*    ENVRLAND                   add land needed to meet animal unit per acre
     OBJECTIVE                  objective funtion for maximizing net revenue;

CONSTEFSYS..  SUM((SYS,APPSYS)$EFFSYS(SYS,APPSYS),TYPE(SYS,APPSYS))
              =E= 1;

TOTAVNUTR(NUTRIENT).. SUM((SYS,APPSYS,TIME)$EFFSYS(SYS,APPSYS),
              TYPE(SYS,APPSYS)*ATTRI(SYS,NUTRIENT)*
              TRANSINFO(APPSYS,NUTRIENT)*TNUTR(NUTRIENT,TIME))
              =E= AVMANNUTR(NUTRIENT);

CONSTAFER(NUTRIENT)..TNUTREQ(NUTRIENT)-AVMANNUTR(NUTRIENT)
              =L= AMFERT(NUTRIENT);

ACFERTVAL..    SUM(NUTRIENT,AMFERT(NUTRIENT)*PRICENPK(NUTRIENT))
              =L= FERTCOST;
```

```
CONSTNEXC(NUTRIENT).. AVMANNUTR(NUTRIENT)- TNUTREQ(NUTRIENT)
              =L= EXCNUTR(NUTRIENT);

ADDLAND(NUTRIENT).. EXCNUTR(NUTRIENT)-
              SUM((CROP,YIELD,TIME)$CROPUSE(CROP,NUTRIENT,YIELD,TIME),
              ALAND(CROP,YIELD)*CROPUSE(CROP,NUTRIENT,YIELD,TIME))
              =L= 0;

BALEQTANK('TSYS3',TIME)..BEGINVTK('TSYS3',TIME) + MWASTEVOL(TIME)-
              MHAULVOLTK('TSYS3','AMHAUL',TIME)
              =L= TANKSIZE;

BALEQPIT(TIME)..BEGINVPT(TIME) + MWASTEVOL(TIME)-
              MHAULVOLPT('PIT','AMHAUL',TIME)
              =L= PITSIZE;

CONSTLABOR(TIME)..   SUM((SYS,APPSYS)$EFFSYS(SYS,APPSYS),
              TYPE(SYS,APPSYS)*MHAULHOUR(SYS,APPSYS,TIME))
              =L= AVALABOR(TIME);

*ENVRLAND..    SUM((CROP,YIELD),ACRENO(CROP,YIELD)+ALAND(CROP,YIELD))-
*              SUM((SYS,APPSYS,ANIMAL)$EFFSYS(SYS,APPSYS),
*              REQACRE(SYS,ANIMAL)*TYPE(SYS,APPSYS))
*              =G= 0;

OBJECTIVE..   SUM((CROP,YIELD),NETRCROP(CROP,YIELD)*ACRENO(CROP,YIELD))+
              SUM(ANIMAL, ANIMALNO(ANIMAL)*NETRSWINE(ANIMAL))-
              SUM((SYS,APPSYS)$EFFSYS(SYS,APPSYS),
              TOTALCOST(SYS,APPSYS)*TYPE(SYS,APPSYS))-FERTCOST-
              SUM((CROP,YIELD), ALAND(CROP,YIELD)*CUSTCOST(YIELD))
              =E= Z;

MODEL MANURE/ALL/;

SOLVE MANURE USING MIP MAXIMIZING Z;

********************************
* DISPLAY
********************************

DISPLAY EXCNUTR.L;
DISPLAY AMFERT.L, AMFERT.M, FERTCOST.L, FERTCOST.M;
DISPLAY ALAND.L, ALAND.M, TANKSIZER.L, PITSIZER.L;
DISPLAY TYPE.L, TYPE.M;
DISPLAY Z.L;
DISPLAY CONSTAFER.M, CONSTNEXC.M, ADDLAND.M, CONSTLABOR.M;
DISPLAY OBJECTIVE.M;
```

2

VITA

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Doctor of Philosophy

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